COLUMN: PRESIDENT'S HOOK

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AFS Annual Meetings: Where the Lure Strikes the Water

With the 2006 AFS Annual Meeting at Lake Placid swiftly approaching, I decided to devote my final column to this remarkable event. Our Annual Meetings have evolved to become occasions of unparalleled magnitude when it comes to information exchange, educational opportunities, social interactions, business endeavors, and networking within the fisheries profession. With each Annual Meeting, we grow our knowledge, expand our networks, renew our enthusiasm, and solidify our commitments for the conservation and sustainable use of aquatic resources. An AFS Annual Meeting is not simply a happening—it is fundamentally where it is happening with respect to all things wet and wild. To illustrate my point, I will provide the highlights of the Annual Meeting to convene this September.

September 6: Annual Meetings may be "happenings," but they don't just happen! The Program Committee and local arrangements folks (they've been on top of this for four years!), officers, and AFS staff all arrive well ahead of the meeting to ensure it runs as smoothly and efficiently as possible. The officers and executive director (ED) start with a dinner meeting where they review the gamut of issues likely to be on the table at various venues of the meeting. Meanwhile, a cadre of organizers and AFS staff are scattered behind the scenes seeing to the details of the meeting.

September 7: The officers and ED spend the morning preparing for a seemingly endless number of business meetings and activities to be taking place before, during, and after the main event. The Management Committee, consisting of the officers, ED, Division presidents, and at-large members elected by the Governing Board, convenes in the afternoon, primarily to deliberate over the upcoming annual budget (we are talking seven figures here!) and the proposed plan of work for the incoming president, Jennifer Nielsen.

September 8: The Governing Board (the Management Committee plus Division presidents elect and Section presidents), as well as the ED and a smattering of other dignitaries, spend the day in a retreat to strategize future services and activities AFS might undertake now that our goal for the reserve fund has been met. Such brainstorming activities provide an opportunity for a diversity of ideas, which often form the basis for subsequent strategic plans. It is in such forums where the sheer energy and intellects of AFS leaders become impressively evident.

September 9: The Governing Board spends an exhausting day approving the annual budget of the Society, deliberating over a multitude of motions and other action items, listening to summaries of Unit reports, and conducting other business as needed to ensure the seamless running of the organization. Simultaneously, some continuing education courses get underway (our Continuing Education Committee has a slate of 11 courses for this meeting alone!). At the Governing Board social that evening, AFS leaders, spouses, significant others, and staff gather in an informal setting for mostly camaraderie and fun.

September 10: The majority of members will arrive this day. Be assured, besides picking up materials at the registration desk, there is much more going on than the evening Welcome Social. More continuing education courses, Section business meetings, and a bevy of committee meetings will be taking place, almost from the crack of dawn. This year's Welcome Social should be a memorable one, as it will be held at the speed skating oval where Eric Heiden won five Olympic gold medals. Preceded by a craft show (with purchases available), it will feature a "Taste of New York" sampling of foods and cultures.

September 11: The technical meeting starts with a bang, literally on the rink of "Miracle on Ice" fame, with a Plenary Session featuring three superstars of our profession, Bonnie McCay, Roy Stein, and Bill Taylor. These engaging speakers will share their perspectives on our annual theme—"Fish in the Balance." Get there early for refreshments and to commandeer a good seat. This is not the time for sightseeing. In fact, besides going to a session where you are personally delivering a presentation, this is the one session you don't want to miss. Our speakers promise to enthrall you, to tantalize you, and to inspire you. There could even be a cameo appearance by a celebrity! The technical sessions begin that afternoon—how does over 1,200 papers and 32 symposia strike you? And, of course, Monday night is devoted to the Trade Show Social, once again, on "the" rink, or Herb Brooks Arena, as it is officially named. Incidentally, visit the Trade Show often, and not just for the coffee breaks. You won't be disappointed.

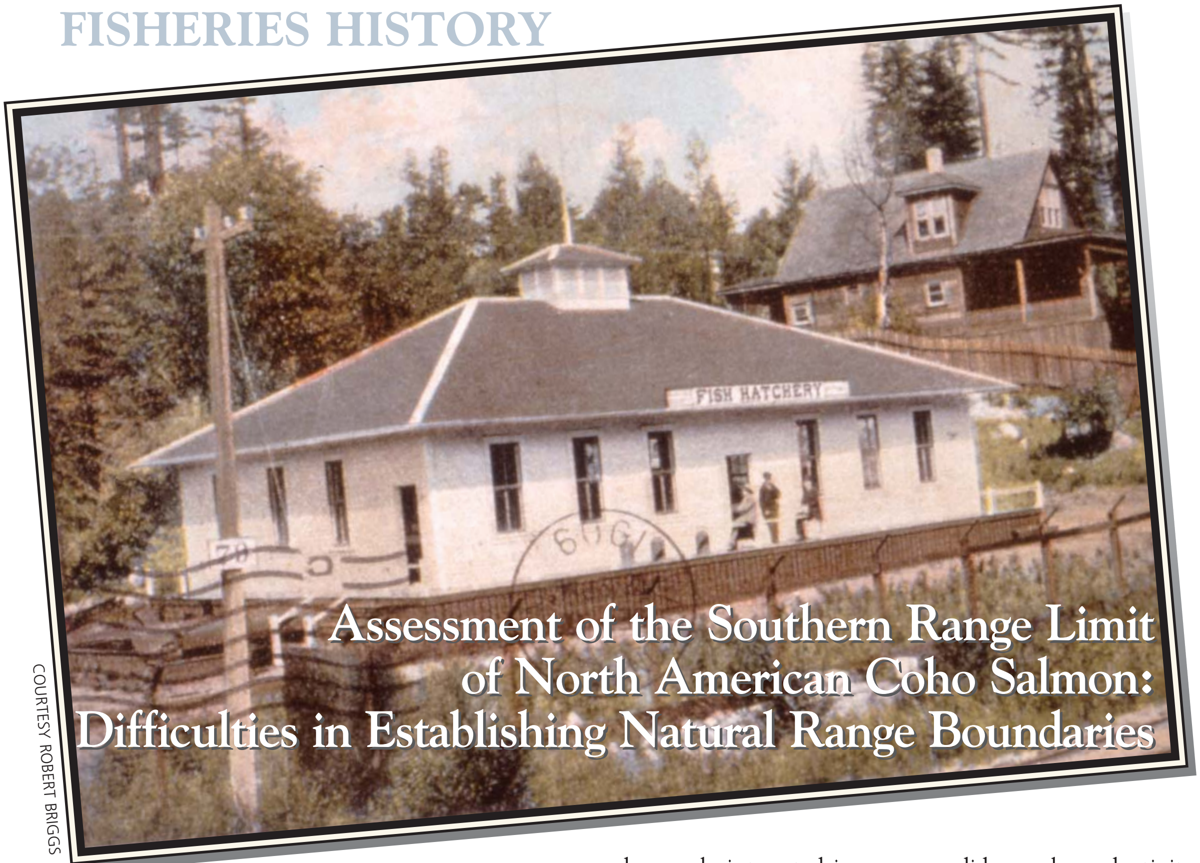
September 12: More technical sessions, more Unit business meetings, and the business meeting of the parent Society are scheduled. Please come to the Society Business Meeting—it is my last chance to thank you for the honor of serving as your president before I turn the gavel over to Jennifer Nielsen. We will focus our attention on students that evening, with a social dedicated to them. Students will have the opportunity to socialize with other students, professionals from around the globe, and potential employers. I have literally witnessed students receiving job offers at these events—now that is networking!

September 13: More of everything takes place on Wednesday, with festivities reaching a climax that evening at the "Fishtoberfest." Expect Olympic demonstrations, even without the snow, and a fireworks display to cap off the evening.

September 14: We don't wind down just yet as the morning begins with the incoming Governing Board breakfast. Meanwhile, technical sessions run throughout the day. That evening there is yet another social, this one to celebrate the meeting just completed and to get a sampling of next year's meeting in San Francisco.

Wow! Is AFS a great organization or what?

Let me close by once again thanking each and everyone of you for bestowing upon me such a magnificent honor. I especially want to thank my fellow officers and Gus Rassam, who did their best to keep me in line, all the other members of the Governing Board, all committee chairs and committee members, the Lake Placid meeting organizers, as well as the entire AFS staff, who do incredible work with not nearly enough recognition. Lastly, I thank my students, staff, and especially my wife, Sue, for extraordinary support over this past year.



Assessment of the Southern Range Limit of North American Coho Salmon: Difficulties in Establishing Natural Range Boundaries

COURTESY ROBERT BRIGGS

Historical Brookdale Hatchery, San Lorenzo River, California.

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ABSTRACT: This study examines whether coastal streams of the Santa Cruz Mountains are within the coho salmon (*Oncorhynchus kisutch*) native habitat range. A critical assessment of all available evidence reveals that the presence of naturally occurring sustainable populations of coho south of San Francisco is improbable. Early scientific surveys, consistent with archaeological data, found no coho south of San Francisco prior to their documented anthropogenic introduction in 1906. This introduction apparently was forgotten, as subsequent researchers only interested in presence did not differentiate the origin of the fish or apparently did not investigate references back to original source documents. As the origin of stocks has become more relevant, the progeny of these and many subsequent hatchery plants of imported coho stocks have been assumed to be indigenous. The planted coho stocks have not thrived. Harsh inland habitat conditions in the Santa Cruz Mountains, primarily in the form of naturally occurring floods and droughts, can eventually eliminate the most robust coho year-class during good decade-scale productivity in the California Current. A net replacement rate analysis of freshwater and marine survival rates helps explain why coho salmon have not been able to establish persistent natural populations south of San Francisco, even after a century of heavy hatchery stocking. These data and their history in the fisheries literature are presented here so they can be open to scrutiny, critique, and reference by other fisheries professionals. This assessment opens a number of questions on how to define the ranges of salmon for practical management purposes.

INTRODUCTION

> Superintendent Shebley also has in process of hatching 50,000 silver [coho] salmon eggs from the Baker Lake Hatchery in the state of Washington. These fish, in their native waters farther north, run up the smaller streams like the steelheads do in this country and if they thrive here as hoped they will prove a valuable addition to the piscatorial tribe of our Santa Cruz waters.
>
> The Brookdale Fish Hatchery
> *The Mountain Echo*
> 24 March 1906

Recently, Gobalet et al. (2004) described archaeological studies of fish use by Native Americans on the California Coast south of San Francisco and the San Francisco Bay area drainage, thus illuminating local prehistoric and early historic California fish distribution. "[N]o coho salmon [*Oncorhynchus kisutch*] were found south of San Francisco on the California coast" in the archaeological record (Gobalet et al. 2004: 814). Consequently, increased scientific attention has opened questions concerning the southern extent of their native range and has motivated the pursuit of more precise information. Many contemporary researchers believe the natural range of coho salmon extended south of San Francisco.

To date, the historical presence of sustainable, native coho populations in any coastal stream south of San Francisco has been inferred but not demonstrated. Several hypotheses regarding the historic status of coho south of San Francisco are:

1. coho salmon maintained a permanent presence south of San Francisco as a metapopulation where individual populations of coho were ephemeral but were mutually supported by straying within the metapopulation or from some straying from metapopulations to the north;
2. coho salmon were historically native but were extirpated prior to any surveys;

3. coho salmon were historically native, were never entirely extirpated, but were repeatedly missed in early surveys; or
4. coho salmon sustainable populations were historically distributed only as far south as San Francisco with occasional ephemeral year-classes further south in some coastal streams (stray spawnings).

The overall weight of evidence, gained from multidisciplinary sources presented here, suggests that the fourth possibility is most probable. We found no undisputed evidence of coho salmon populations in streams south of San Francisco, prior to artificial introductions beginning in 1906, in archaeological, historical, or other scientific or popular records. On the contrary, a compelling number of complementary sources indicate that self-sustaining populations of coho were historically absent. In particular, we discovered a 1906 planting of coho salmon by the county of Santa Cruz that Stanford ichthyologists, hatchery personnel, and the local public believed was an introduction of a new species to the area. Other more ambiguous sources were found to be inconclusive. Recently discovered museum specimens may suggest an early coho presence (probably ephemeral) but this remains open to interpretation. A review of the current literature reveals how the assumption that coho are native south of San Francisco was introduced and perpetuated into the current scientific literature with no supportable evidence.

NEED FOR INFORMATION ON THE EXTENT OF ANADROMOUS FISH DISTRIBUTION

Knowledge of the historical presence and extent of southern coho distribution is important for restoration planning and future management decision-making. Coho salmon south of San Francisco are currently listed as endangered under the federal Endangered Species Act and the California Endangered Species Act. The resulting Recovery Strategy for California Coho Salmon (CDFG 2004) proposes to restore sustainable populations of coho in as many as nine coastal streams south of San Francisco (Figure 1). Yet, it is unclear that sustainable populations of coho existed in any of these streams prior to hatchery introductions, or to what extent, if at all, these hypothetical historic populations persisted. To list species as threatened or endangered based on incomplete or questionable scientific and historic data can work a grave and undue hardship on local residents and others who depend on natural resources utilization.

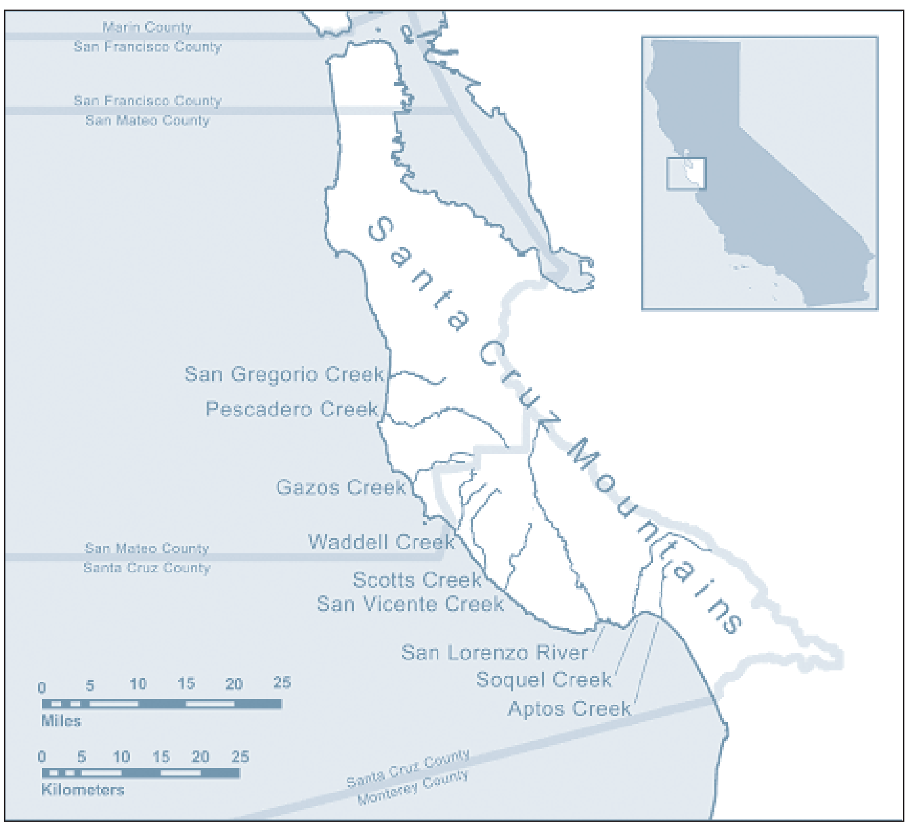
METHODS

We began by tracing to their origin all references in the current literature concerning the historical presence of coho south of San Francisco. "Historical" is defined here as the years from European colonization to the first documented local hatchery plants of coho in 1906 (some authors have not been clear with their use of "historical," using data from the last 50 years, including times of heavy hatchery influence, to infer a native presence and historical abundance). We widened our scope to include the archaeological record, early (1880–1910) scientific literature, historical documents, and government documents. We summarize these sources, discuss their relative reliability and provide an analysis to explain the emergent pattern based on these results, genetics, stream habitat, ocean conditions, and logical reasoning.

6200 BC–1880 AD

Prior to European colonization and the first scientific stream surveys south of San Francisco, local Native Americans actively managed the Santa Cruz Mountains (primarily with fire), and available sources of dietary protein were readily exploited (Evarts and Popper 2001; M. Hylkema, California State Parks Archaeology, pers. comm., 2005). We may never know the full impact of these activities on native fish populations; however, the archaeological record suggests coho salmon did not occur in streams south of San Francisco Bay in these early historic and prehistoric times. It is a basic archeological assumption that fish bones found in Native American refuse middens were discarded food remains. No coho salmon bones or unspecifiable *Oncorhynchus* remains have been found in detailed archeological studies of coastal Native American refuse middens in San Mateo and Santa Cruz counties covering the period 6200 BC–1830 AD (Gobalet 1990; Gobalet and Jones 1995; Gobalet et al. 2004). Conversely, out of the four coastal counties north of San Francisco that were identified by Gobalet et al. (2004:822-823, Table 6) two contained coho remains while three of the four counties yielded unspecifiable *Oncorhynchus* remains. Likewise, out of six San Francisco Bay area counties (Gobalet et al. 2004:822-823, Table 6), two contained coho remains while all six yielded unspecifiable *Oncorhynchus* remains.

Figure 1. Streams south of San Francisco subject to the Recovery Strategy for California Coho Salmon (CDFG 2004).



A larger sample of the archaeological record would undeniably increase the confidence level. However, any interpretations of the archaeological record will have uncertainty. While the archaeological record alone cannot be relied upon to demonstrate presence/absence, it is an indication that coho salmon did not occur in streams south of San Francisco Bay in early historic and prehistoric times. More importantly, it is the only information available regarding the prehistoric presence of coho south of San Francisco prior to the influence of European populations.

Beginning in 1849, the Santa Cruz Mountains were extensively logged. Logging in the different watersheds was staggered over decades and some streams were spared due to the technological limitations of the time (Stanger 1967; Hamman 1980; Dillon 1993; Evarts and Popper 2001). These activities impacted local streams and fish populations. Sawmills, paper mills, tanneries, and other industries dumped pollutants in some streams and locally their impacts were more detrimental. The overall effect of these unregulated historical activities had to be significant. However, steelhead (*O. mykiss*) populations apparently persisted and remained a major attraction for anglers (Hallock 1877). On the other hand, due to their more restrictive life cycle, coho salmon, if present, may have been extirpated south of San Francisco during this time. If so, these hypothetical native populations did not persist (second hypothesis).

PRESENCE / ABSENCE LITERATURE PRIOR TO HATCHERY INTRODUCTION

Coho salmon populations apparently were not found south of San Francisco prior to hatchery fry stockings beginning in 1906. The early coho salmon distribution literature stated that coho salmon were not found south of San Francisco or were only found north of San Francisco (Jordan and Gilbert 1876–1919; Jordan et al. 1882; Jordan 1892a, b, 1894, 1907, 1940a,b; Jordan and Evermann 1896, 1902, 1905;).

Stream surveys were made in this later historical period. Thompson (1922:165) stated,

> In 1880, at the time Jordan made his survey of our coast fisheries… Other surveys occurred in 1889 to 1892, 1904, and 1908.

Leinald (1906) reported that Frank A. Shebley made stream surveys in Santa Cruz County to locate fry release sites from the Brookdale Hatchery. Shebley and Gillis (1911) also noted that Shebley made field surveys of local Santa Cruz County streams to locate the Brookdale Hatchery and the Scotts Creek egg-taking station. Streig (1991) stated that in 1902 Santa Cruz County hired Shebley and Charles H. Gilbert to locate the hatchery site. The Brookdale site was chosen on the San Lorenzo River. The broodstock selected was steelhead and the Scotts Creek site was later chosen for egg taking because it was a small creek (easy to collect adults) and it had a good run of steelhead. Coho salmon were not found during these early surveys on what were the most likely streams in Santa Cruz County to foster populations of coho.

GOVERNMENT DOCUMENTS AND THE SOFT LITERATURE

In 1905 the county of Santa Cruz established the Brookdale Hatchery on the San Lorenzo River (Shebley and Gillis 1911; Shebley 1922; Streig 1991). The hatchery was primarily intended to hatch steelhead trout and potentially introduce Chinook salmon (*O. tshawytscha*) until David Starr Jordan suggested the Brookdale Hatchery introduce coho salmon (Jordan 1861–1964, as archived).

In 1906, following the successful propagation of steelhead trout, 50,000 coho salmon eggs (in addition to 1 million Chinook salmon eggs) were delivered to the Brookdale Hatchery from the federal Baker Lake Hatchery in Washington state, as reported by the U.S. Bureau of Fisheries (Bowers 1907). Bowers (1908, 1909, 1910, and 1911) reported additional federal coho salmon egg deliveries to the Brookdale Hatchery over the next several years (Table 1).

Year	Eggs
1906	50,000
1907	100,000
1908	100,000
1909	50,000
1910	100,000 and 100,000
1911	2,289,900 delivered to California (The delivery to Brookdale was not broken out.)

Table 1. U.S. Bureau of Fisheries coho salmon egg deliveries to the Brookdale Hatchery from 1906 to 1910 (Bowers 1907, 1908, 1909, 1910, 1911). The 1911 allocation of coho salmon eggs in California is unclear (Bowers 1912).

Newspaper and sporting journal articles help illuminate the initial coho salmon hatchery efforts at the Brookdale Hatchery and the early presence/absence of coho salmon in Santa Cruz County (Mountain Echo 1905, 1906a,b, 1907; Santa Cruz Morning Sentinel 1905, 1906; Welch 1907; A. P. B. 1909). The *Santa Cruz Morning Sentinel* (7 March 1906: 1) stated,

> Dr. Shebley has 50,000 silver [coho] salmon eggs from Baker Lake Washington which will be hatched out in a short while.

Another Santa Cruz County newspaper article (*Mountain Echo* 16 December 1905:3) titled "Our County Fish Hatchery" stated,

> Superintendent Frank Shebley… expects to receive...silver [coho] salmon eggs from the U.S. government hatchery in the state of Washington. It is believed if raised and planted here they will frequent our streams and thus give us another valuable game fish.

Reporting on the 50,000 coho salmon eggs that were received from the federal Baker Lake Hatchery in Washington, an article in *The Mountain Echo* (24 March, 1906a:3) stated,

> If they thrive here as hoped they will provide a valuable addition to the piscatorial tribe of our Santa Cruz waters.

Forest and Stream Journal editor Welch reported (13 July 1907:76) that,

> During 1906 Mr. Shebley hatched and liberated in the streams of the county upward of…50,000 silver [coho] salmon [fry]. The hatching of the silver [coho] salmon is an experiment that is being considered by Mr. Shebley in connection with the United States Fish Commission, with the hope of introducing into the streams of the county a new species of fish...it is to be hoped that the silver [coho] salmon…return to the streams of the county to spawn thus adding a new species of both game and food fish to the already well supplied waters of [Monterey] bay.

It seems likely, if coho salmon were already present, Shebley (and the federal government) would have used this local source for coho salmon eggs instead of going to the trouble and expense of importing coho salmon eggs from Washington state. Shebley would have needed only about 20–30 female coho salmon to yield 50,000 eggs. Evidently, the Brookdale Hatchery importations of Baker Lake coho were an intentional effort to introduce a new species. Thus, the soft literature suggests that coho salmon were not present in Santa Cruz County streams prior to their introduction in 1906. This reinforces the earlier presence/absence scientific literature and the equivocal archaeological data.

Shebley and Gillis (1911) and Shebley (1922) stated that fry hatched at Brookdale were distributed in streams in Santa Cruz, San Mateo, Santa Clara, and Monterey counties. The National Marine Fisheries Service (Bryant 1994), the California Department of Fish and Game (Anderson 1995; Baker et al. 1998), and others (Streig 1991) summarized the history of coho salmon hatchery planting in Santa Cruz County but missed these critical early stocking records.

COHO SALMON LITERATURE AFTER HATCHERY COHO INTRODUCTION

Little is known about coho abundance south of San Francisco prior to 1933. Similarly, surviving reports of fish planting activities south of San Francisco are generally not very detailed. Thus, this important historical information has been poorly documented and written summaries have featured extrapolations.

First Observations of Adult Coho Salmon

The first record of adult coho salmon stream occurrence south of San Francisco may be a 1909 sporting journal letter stating,

> The silver-sided [coho] salmon have been hatched at the Brookdale Hatchery and much is expected from this fine fish. The first planting in this state [coho fry in spring 1906 returning as adults in late fall 1908] was made in the San Lorenzo River and a number [of adults] have been taken this fall [1909 from the 1907 fry outplanting] making a run up that stream.
>
> A.P.B. 1909: 862

Later, the Fish and Game Commission's 1913 Biennial Report mentioned coho salmon "as far south as the Monterey Bay" (Newbert et al. 1913:30). Snyder (1914:70) stated, "Silver salmon were said to have been observed in the San Lorenzo River at Santa Cruz." Although stocking success can be variable, these literature statements appear to indicate that some coho salmon had been established in Santa Cruz County by 1909.

The Scotts Creek Egg-Taking Station

In 1909 the state leased the Scotts Creek egg-taking station (principal adjunct to the Brookdale Hatchery) from Santa Cruz County and enlarged it "so as to take an extra number of steelhead eggs" (Newbert et al. 1913:36). It would seem the egg station was originally planned for just steelhead trout as no mention was made of any intent to collect coho salmon (Van Sicklen et al. 1910). This suggests that coho salmon were either not present or at least not abundant enough at Scotts Creek to be a good source of coho eggs. In fact, all early California Fish and Game Commission Biennial Reports mention only steelhead trout in relation to the Scotts Creek egg-taking station. Apparently, the Brookdale Hatchery fish trap on the San Lorenzo River also was not a viable source of coho eggs as there are no records of coho collected at that station. The U.S. Bureau of Fisheries shipments of coho eggs to the Brookdale Hatchery (Bowers 1907, 1908, 1909, 1910, 1911) are relevant in this regard.

Streig (1991) reported that the Scotts Creek Egg Taking Station took 1.4 million coho salmon eggs in 1909. He estimated these eggs came from 518 female coho based on his estimated egg-to-female ratio. Five hundred and eighteen female coho in Scotts Creek would be unlikely from the Brookdale Hatchery's 1907 fry outplantings alone, suggesting that coho salmon were already established in Scotts Creek. Streig (1991) cited no references. Apparently the figure 1.4 million came from the 21st Biennial Report of the California Board of Fish and Game Commissioners (Van Sicklen et al. 1910). The report stated 3,582,000 eggs were hatched at the Brookdale Hatchery, of which 2,182,000 were steelhead. The remaining 1.4 million eggs were listed as "salmon;" Streig apparently interpreted these as coho salmon. However, these were not coho salmon eggs harvested from 518 coho salmon from Scotts Creek. The U.S. Bureau of Fisheries shipped 1 million Chinook eggs and 200,000 coho eggs to the Brookdale Hatchery that season (Bowers 1911), equaling 1.2 million eggs not collected from any local streams. The Brookdale Hatchery also operated fish traps on Soquel Creek and on the San Lorenzo River, targeting steelhead and Chinook salmon. The remaining 200,000 eggs were probably Chinook eggs from returning females from the 2.3 million Chinook fry planted in 1906 and 1907 (Bowers 1907, 1908). Other authors (Hope 1993; Bryant 1994; Anderson 1995; Baker et al. 1998; NOAA 2004b) have taken the 518 female coho estimate as evidence that coho salmon were native south of San Francisco. Also pertinent is that no coho salmon eggs were collected at the Scotts Creek Egg Taking Station in 1908, 1910, 1915–1921, and 1924–1926 (years when data were found; no data for 1911–1914 and 1922–1923; Streig 1991; Bryant 1994). These data reinforce the invalidity of the 1.4 million coho eggs and subsequent 518 female coho salmon estimate for 1909.

1910–1990

In 1910 large plants of coho in the Klamath and Sacramento Rivers were reported by the California Fish and Game Commissioners as "the first effort made in this State to increase the runs of the silver salmon" (Newbert et al. 1913:30). While this appears to contradict the earlier coho plants beginning in 1906, this statement may reflect that the state did not take over operations at the Brookdale Hatchery and adjuncts until 1912 (Leitritz 1970). These Biennial Reports of the Fish and Game Commission have become our primary source of information about early fish cultural activities in California; unfortunately, early records at the Brookdale Hatchery have not survived. Failure to acknowledge the prior coho plantings by the county of Santa Cruz causes these Biennial Reports to contribute to the subsequent assumption that coho were native.

During the midwinter of 1910–1911, Gilbert and Shebley fin-clipped an unspecified number of coho yearlings in Scotts Creek (Gilbert 1914) but the origin of these fish was not discussed. Ricker (1972: 28) stated, "One fish was as good as another" during that era and eggs were moved from hatchery to hatchery and fry from stream to stream. Streams in California received frequent out-of-basin coho salmon transfers. California Fish and Game Biennial Reports recorded Brookdale Hatchery coho distributions in Santa Cruz and surrounding counties but the origin of these fish was generally unstated. According to these reports, the Brookdale Hatchery planted locally 25,000 and 71,000 coho of unstated origin in 1913 and 1915, respectively (Newbert et al. 1914, 1916). However, according to recent documents by the California Department of Fish and Game (Anderson 1995; Baker et al. 1998) and the National Marine Fisheries Service (Bryant 1994), these coho (plus an additional 15,000 in 1913) were actually from the Mount Shasta Hatchery. Unfortunately, the data were not cited and we were unable to substantiate them. The

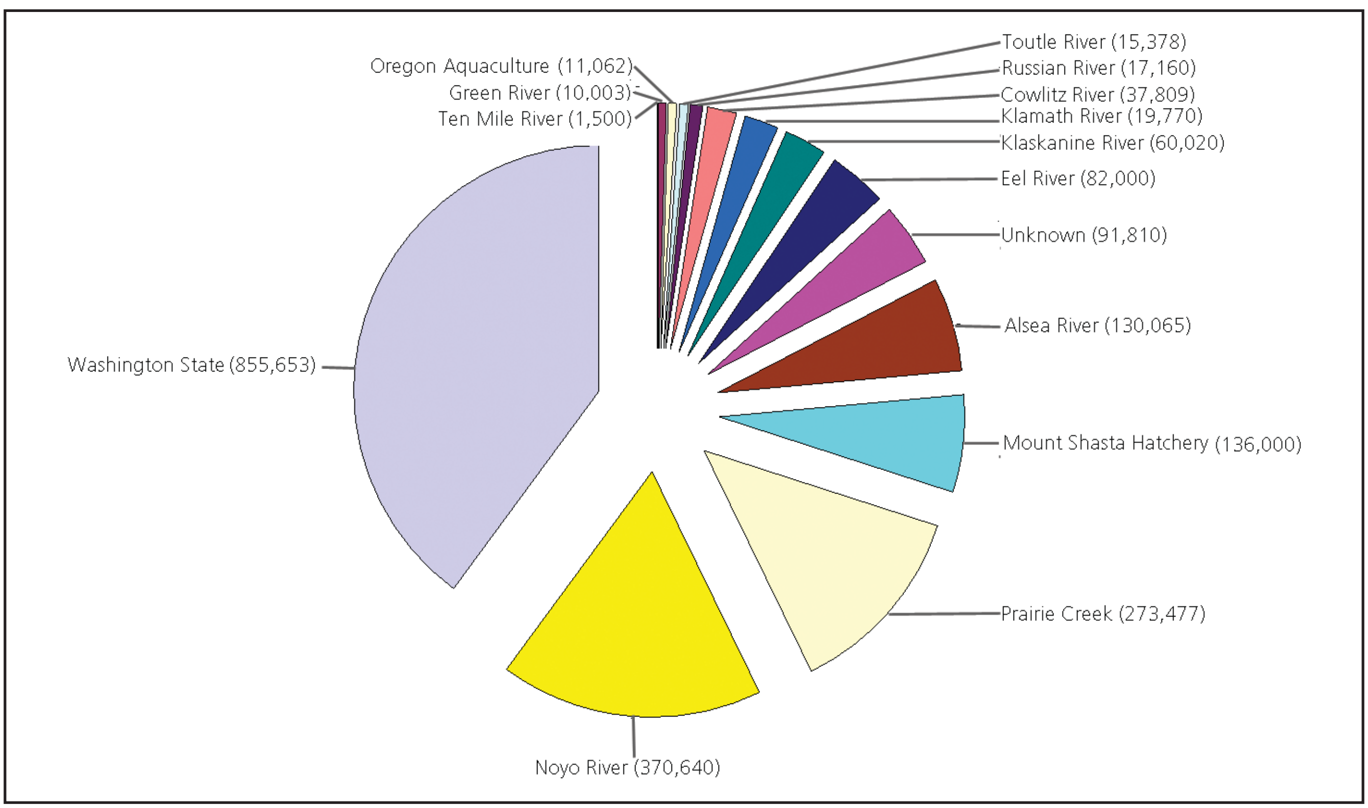
California Department of Fish and Game (Anderson 1995; Baker et al. 1998) and the National Marine Fisheries Service (Bryant 1994) also stated the Brookdale Hatchery planted 25,000 coho in 1917, but again we were unable to verify this as it does not appear in the older Biennial Reports (Newbert et al. 1918) nor other records of which we are aware.

Due to water shortages at the Brookdale Hatchery in the early 1920s, the Fish and Game Commission proposed a new hatchery on Big Creek, tributary to Scotts Creek (Newbert et al. 1924; Zellerbach et al. 1927). The Big Creek Hatchery began operations in 1927 (Zellerbach et al. 1928; Leitritz 1970). In 1929, during the worst drought of the century and three years prior to the Shapovalov and Taft study (initiated in 1932 and ultimately published in 1954), the Brookdale Hatchery planted 281,200 coho of unknown origin in Santa Cruz County (Zellerbach and Fernald 1930). The following year (1930) the Brookdale Hatchery and the Big Creek Hatchery planted 135,500 and 43,325 coho of unknown origin, respectively (Gentry et al. 1932; Dayes 1987).

In 1932, the Brookdale Hatchery distributed 32,000 coho in Santa Cruz County (Gentry et al. 1934). Again, Fish and Game Biennial Reports did not state the origin of these fish, but a few surviving Brookdale Hatchery records indicate 50,000 coho were imported from the Fort Seward Hatchery on the Eel River that season, of which 32,400 were planted (Dayes 1987). Similarly, Biennial Reports indicate the Brookdale Hatchery distributed 55,627 coho of unstated origin in 1933, while hatchery records show it was actually 54,685 coho from the Prairie Creek Hatchery. Thus, assumptions by prior authors that coho eggs of unstated origin were locally harvested are untenable.

The first actual record of coho salmon eggs of local origin hatched and planted south of San Francisco does not appear until 6 January 1934 (Dayes 1987). Also in the winter of 1934, Shapovalov and Taft (1954) made the first measurements of coho abundance south of San Francisco at Scotts and Waddell Creeks in northern Santa Cruz County. From 1934 to 1939, throughout most of the Shapovalov and Taft study, the Brookdale Hatchery and the Big Creek Hatchery distributed about 645,500 coho from Scotts Creek, Prairie Creek (in northern California), and unknown sources (Moore et al. 1936,1938; Milnor et al. 1940; Dayes 1987). In addition, the Brookdale Hatchery made one final plant of 14,685 coho of unknown origin in 1941 (Milnor et al. 1944). Unfortunately, Shapovalov and Taft's information did not identify the origin of the coho nor did they discuss hatchery activities in any detail. The California Department of Fish and Game (Anderson 1995), the National Marine Fisheries Service (Bryant 1994; MacFarlane and Alonzo 2000), and Brown et al. (1994) acknowledged these plants, but calculated historical declines based on the Shapovalov and Taft study (1954) and attributed those declines to land use activities. Streams such as the San Lorenzo River continue to experience habitat degradation (primarily due to residential development) but environmental quality on streams such as Scotts and Waddell creeks is good to excellent (Smith et al. 1997; Smith 2001; West 2002; SCWC 2005). Thus, it can be seen that the role of hatchery influence has often not been included in calculations

Figure 2. Numbers of coho salmon from Northern California, Oregon, and Washington that were planted in streams south of San Francisco from 1906 to 1990. (data from Bowers 1907, 1908, 1909, 1910, 1911, 1912, 1913; Gordon et al. 1958; Streig 1991; Bryant 1994; Anderson 1995; Baker et al. 1998; NOAA 2004). The Washington state category includes the categories "Washington University," "Washington U./Klamath R.," and "Washington state" as reported by Baker et al. (1998).



on historical population trends south of San Francisco.

Operations at the Big Creek Hatchery and the Brookdale Hatchery were discontinued in 1939 and 1953, respectively. We could find no reports of coho salmon hatchery plants in Santa Cruz County from 1942 to 1962, save one plant of 46,160 coho of unknown origin in 1956 by the California Department of Fish and Game (Gordon et al. 1958). From 1963 to 1990 (the last year coho were imported into Santa Cruz County), approximately 1,750,000 coho were planted south of San Francisco by the California Department of Fish and Game, Pacific Marine Enterprises (a private salmon ranching venture also known as Silver-King Oceanic Farms), and the Monterey Bay Salmon and Trout Project. About 70% of these coho were imported from California (north of San Francisco), Oregon, and Washington (Baker et al. 1998). The Monterey Bay Salmon and Trout Project operates the Big Creek Hatchery near Scotts Creek; the hatchery was reestablished in 1982. The Monterey Bay Salmon and Trout Project no longer imports coho salmon. The Big Creek Hatchery (also known as the Kingfisher Flat Hatchery) is currently operated as a strict conservation hatchery and is solely responsible for the continued coho presence south of San Francisco (Smith 2005). All coho salmon found today in Scotts and Waddell creeks are of hatchery origin (D. Streig, Monterey Bay Salmon and Trout Project, pers. comm. 2005), and as of 2003, there was only a single viable year-class of coho south of San Francisco (Smith 2004).

COHO SALMON SOUTH OF SAN FRANCISCO—GENETICS

Bryant (1994) concluded from genetic allozyme analysis, life history characteristics, and behavior that coho salmon south of San Francisco were not distinct from coho salmon populations to the north. Anderson (1995) concluded that gene flow among California coho populations (including populations south of San Francisco) was high. It had to be, considering the multiple stock plants that had occurred (Figure 2). Bryant (1994:62) stated,

> Although Scott and Waddell Creeks are generally considered to have the last remaining naturally reproducing coho salmon populations south of San Francisco, extensive hatchery plants of non-native stocks have taken place from the early 1900s through the 1970s from a variety [of] watersheds throughout the west coast.

As quoted earlier, Ricker (1972) stated that early fish researchers regarded populations of the same species as genetic equivalents everywhere. Brown et al. (1994: 252) concluded that plants from Oregon and Washington caused the swamping and homogenization of native California gene pools. They quoted, "…Waddell Creek fish had the highest level of heterozygosity for any California coho salmon population, presumably as the result of interbreeding with imported stocks." High heterozygosity within a population indicates that it has had much gene exchange with other populations (high genetic diversity).

More recent genetic analyses (Hedgecock et al. 2002; Garza 2003, 2004, unpublished data; Bjorkstedt et al. 2005) are inconclusive with regard to the historical origins of coho south of San Francisco. The latest genetic data appear to show that the stocks south of San Francisco are related to neighboring northern stocks. Following the initial 1906–1910 introductions, the majority of imported fish were of neighboring California stocks which, combined with straying, could result in genetic affinities. The latest genetic data for the stocks south of San Francisco do not support concordance between genetic and geographic population structure.

In response to criticisms that their study lacked a historical perspective on stock transfers, Hedgecock et al. (2002:66) responded,

> We welcome the information regarding the history of the Waddell Creek and Scott Creek coho salmon populations, which may provide insight into their genetic affinities. It is unfortunate that this information has not been published in peer-reviewed journals.

This type of approach underscores the need for reliable historical information.

STRAY RATE IMPACT IS SIGNIFICANT

Stray rates are also significant with regard to genetics and to the native coho issue. Shapovalov and Taft (1954) estimated that straying of marked coho salmon between Scotts Creek and Waddell Creek ranged from 15–27%. Bryant (1994) considered the Shapovalov and Taft (1954) stray rates as minimums and noted that several tagged coho salmon from Waddell Creek strayed to the Noyo River (322 km north) and several strayed to the San Lorenzo River (south 24 km). These stray rates are not atypical for hatchery-derived coho salmon, well within the reported straying ranges (Bryant 1994). The California

Table 2. Stray effect analysis using a conservative 20% stray rate (roughly halfway between the 15 and 27% Shapovalov and Taft 1954 stray rates) and coho salmon outplants from the Monterey Bay Salmon and Trout Project hatchery into the San Lorenzo River or Scotts Creek (Streig 1991 as reported by Bryant 1994). A 3% marine survival estimate is used.

Year	Stock Used	Released Juveniles	Returning Adults	Adult Strays
1984	Russian River	17,160	515	103
1986	Unknown	15,860	476	95
1988	Noyo River	20,822	625	125
1988	Scotts Creek	6,000	180	36
1988	Scotts Creek	2,450 (a)	73	20 (b)
1989	Noyo River	25,362	761	152
1989	Scotts Creek	2,756 (a)	83	22 (b)
1990	Prairie Creek	34,500	1,035	207
1990	Scotts Creek	6,550 (a)	196	53 (b)
1991	San Lorenzo	19,800	594	119
1991	Scotts Creek	5,040	151	30
1991	Scotts Creek	5,460 (a)	164	44 (b)
1992	San Lorenzo	1,872	56	11
1993	San Lorenzo	11,800	354	71
1993	Scotts Creek	1,860 (a)	56	15 (b)

(a) Released into Scotts Creek.
(b) Strayed into Waddell Creek at a 27% stray rate per Shapovalov and Taft (1954).

Department of Fish and Game (2002) reported stray rates of up to 67% for hatchery plants in California.

The estimates in Table 2 indicate an ongoing infusion of nonnative hatchery stray coho salmon into Scotts and Waddell creeks from coho planted in the San Lorenzo River by the Monterey Bay Salmon and Trout Project is likely.

ANOMALOUS INFORMATION

Captain Wakeman

An uncritical reading of an anecdotal report by a Captain Wakeman (Skinner 1962) suggested coho were present south of San Francisco in the late 1800s. The then newly established California Fish Commission employed Captain Wakeman in 1870 to determine the extent and condition of fisheries of the San Francisco Bay as well as some of the neighboring coastal streams (Redding et al. 1872). Alvarado (2003) addressed the many credibility issues associated with the Wakeman report: lack of expertise, contradictions, and exaggeration. Ignoring these issues, we can address what was reported from a fisheries perspective. Wakeman reported what local fishermen were telling him. They fished at the mouths of San Gregorio and Pescadero creeks at high tide and their fishing season was from October to March. They caught "a wagonload" of fish a day (quite a good fishery if true). Wakeman wrote of two species of fish being caught, "salmon" from 15 to 20 pounds, and "silver salmon" from 2 to 15 pounds. This appears reasonable. The "salmon" reference was most likely to fall Chinook salmon, not coho salmon, because the large weight reported is consistent with Chinook and not coho salmon. The fishing season beginning in October is more consistent with Chinook; a coho run would be later. The identification of the second fish reported caught must be steelhead since Wakeman reported that this fish returned to sea after spawning. Steelhead return to the sea after spawning; coho salmon do not. Commercial fishermen would recognize a spawned-out fish because the fish would be noticeably thinner, probably darker in color, and the flesh would be inferior to a bright incoming fish. Further, if they used gill nets, the sea-bound adult steelhead would be caught in the upstream side of the net. This second fish's size is consistent with steelhead runs having fishes of varying sizes depending on their time spent maturing in the ocean, here probably up to three years. Adult coho salmon can vary in size from year-to-year but within a year-class and stream, size is fairly consistent because the adults have spent 18 months at sea, part of their fixed 3-year life cycle. The protracted spawning season is also more consistent with steelhead. This identification of the two species of fish Wakeman described is consistent with the distributions of Chinook salmon and steelhead reported in the early scientific literature south of San Francisco. The only possible confusing point is that Wakeman called the second fish "silver salmon." In today's vernacular, this would mean coho salmon, but "silver salmon" was historically a very ambiguous common name among laymen in California (Snyder 1931). In fact, in 1873, (prior to Jordan's survey of the Pacific Coast in 1880) it was believed there were 22 anadromous species on the Pacific Coast (Hallock 1877) and 43 species of salmon and trout (Goode 1884). To rely on Wakeman's use of the term "silver salmon" as evidence that coho salmon were historically native south of San Francisco, one would be hard pressed to explain the biological contradictions of the Wakeman report. Additionally, Jordan (1887) made a site visit to the mouth of Pescadero Creek. He reported that a commercial fisherman caught salmon and trout there. At that time "salmon," as used by Jordan, only referred to Chinook salmon. In a previous section of the same report, Stone (1884:479) stated, "On the Columbia River the name 'Chinook Salmon,' is in universal use. Farther south the name 'Salmon' is applied to this species, while the others receive specially distinctive names." This information compliments the biological interpretation given here of the Wakeman report and helps invalidate Skinner's (1962) coho presence record based on Wakeman's use of the term "silver salmon" to describe steelhead trout.

California Academy of Sciences Specimens

Fifteen pertinent juvenile fish specimens reportedly were collected at two Santa Cruz County streams (Scotts and Waddell creeks) by a Stanford University expedition, which according to date inclusions in two jars, occurred in 1895 (California Academy of Sciences 1895a,b). Three additional juveniles apparently were collected at two other Santa Cruz County streams (San Vicente and Gazos creeks) although these collections are undated (California Academy of Sciences No Date–a,b). These 18 specimens are the best existing evidence that coho salmon possibly were native south of San Francisco. Still, there are several reasons why this evidence is insufficient to establish a self-sustaining historical presence.

The Stanford accession register (which contains no dates and does not appear to be in chronological order) and two original Stanford labels identify the juvenile fish as chum (*O. keta*) and Chinook specimens, not coho. Secondary labels were later added identifying them as coho, with no date, signature, or other way to trace their accountability. D. Catania (California Academy of Sciences, pers. comm. 2005) believes that the second labels identifying the specimens as coho salmon were done while the specimens were at Stanford and before they were transferred to the California Academy of Sciences collection. He stated that all of the transferred specimens have recently been located and examined as to species identity and that all but one of the present specimens are coho salmon. Prior to 1999 the specimens were catalogued in the California Academy of Sciences database as chum and Chinook specimens, not coho.

As a result of the accession log, the initial species identifications (as chum and Chinook), and the unattributed second identity labels (as coho), the chain of custody has been broken and the reliability of the specimens is questionable. In addition, Bohlke (1953), in a *Stanford Ichthyological Bulletin*, adds further doubt as to the veracity of these specimens:

> The early morning of April 18, 1906, saw much damage to the Stanford buildings as a result of the San Francisco earthquake (the San Andreas fault is only four miles west of the campus). The fish collections took their share of the damage. More than

> 1,000 jars and bottles were broken although the majority survived intact. The wreckage lay on the floor, kept wet with water from hoses manned day and night by Professors Snyder and Starks, until new bottles and alcohol could be secured. An effort was made to match specimens and data, this work being done by each member of the entire ichthyological group who had most actively been working on the specimens concerned. As a result much was saved that might have been lost, although there were numerous instances in which the material had to be discarded. In others, some doubt could not be avoided. A small printed label stating "Bottle broken during earthquake" was inserted in each bottle. Unfortunately, according to Prof. J. O. Snyder, a careless curatorial assistant later removed these labels from about half of the jars bearing them...The earthquake damage [also] caused a major change in curatorial routine. Previously, a tin tag bearing the register number was merely dropped into each bottle, together with the original paper work labels. Subsequently, a tin tag register number was tied securely to each specimen....
>
> (Bohlke 1953: 3)

Are the existing specimens and dates the original specimens and dates or were they switched with other specimens or labels on the floor? The broken chain of custody, the original scientific identifications as Chinook and chum salmon, and doubts about the continuity of the specimens, make the scientific reliability of the remaining specimens and dates suspect. Unfortunately, recent attempts to extract DNA from these specimens have failed, probably due to the presence of formalin in the tissue (J. C. Garza, NOAA, pers. comm. 2005). Nevertheless, even if the dates, locations, and species identifications associated with the specimens were valid, these specimens are not by themselves evidence of a persisting native population of coho south of San Francisco.

There were some obscure fish planting activities prior to 1895 (*Santa Cruz Morning Sentinel* 1878; Jordan 1887; Leitritz 1970; Environmental Science Associates 2004). Also, ephemeral (temporary) salmon year-class colonies established by strays are not uncommon, particularly just beyond the fringes of a biogeographic range boundary (Sandercock 1991; Nickelson and Lawson 1998). Sandercock (1991) stated that coho are able to extend their normal ranges through straying. Given the benefit of all doubts, these specimens could represent a temporary propagule year-class coho colony (commonly called "strays" in salmon literature). There were very large commercial salmon landings in California in the early 1890s and apparently 1892 was a record harvest not attributable to any efforts in artificial propagation (Redding et al. 1892). Large runs would have encouraged straying. A cool climatic cycle began around 1890; this would have been benefited salmon. Further, a cool productive California Current cycle should also have occurred as its cycles are correlated with inland climatic cycles. If the California Academy of Sciences specimens do represent a stray year-class colony, it did not persist. The early scientific surveys and soft literature discussed above speak to the absence of coho salmon south of San Francisco prior to 1895 and in the early 1900s before the introductory plants in 1906.

A possible explanation for the extirpation of this hypothetical stray colony is the 1898–99 drought reported by the California Department of Water Resources (Snow 2004). U.S. Weather Bureau records (McAdie 1898) indicate annual precipitation in Santa Cruz was only 13.87 inches in 1898. Only twice during the last century (1917 and 1929) has annual precipitation in Santa Cruz been as low (CDEC 2005). Since 1929, annual precipitation in Santa Cruz has exceeded 15 inches, even during a drought in the 1970s that extirpated the coho populations from nearly every stream south of San Francisco (only two streams retained a single year-class).

Speculation aside, the significance of the subject California Academy of Sciences specimens is not clear with regard to the question of the native status of coho salmon south of San Francisco. Even if the specimens are the original juvenile fish it is likely that they came from stray spawnings and represent ephemeral populations, the fourth hypothesis.

LIKELY REASONS COHO SALMON DID NOT NATURALLY ESTABLISH PERSISTING NATIVE POPULATIONS SOUTH OF SAN FRANCISCO

Stray coho salmon from streams north of San Francisco may well have entered central California coastal streams from time to time and possibly spawned. The migration/stray distance is not unreasonable (Bryant 1994). However, late or nonexistent seasonal rain needed to raise stream flows and breach stream-mouth sand bars, plus devastating floods characteristic of the Santa Cruz Mountains undoubtedly made successful spawning by stray coho adults from the north problematic. Under ideal conditions, a localized, numerically small, single year-class of coho salmon could result from such occasional strays. Brown and Moyle (1991) noted that stray coho reproduced occasionally in San Gregorio Creek (citing Coots 1973. They also stated that a juvenile coho was caught in Pescadero Creek and five were caught in San Vicente Creek in 1981. They stated that occasional stray spawning "… might conceivably found new populations." So why did probable occasional stray coho spawnings fail to persist? Why did coho populations south of San Francisco begun as hatchery introductions fail to maintain three viable year-classes even with recurrent hatchery support? The simplistic explanation is past and present habitat disruption due to human activities, which varies dramatically from stream to stream. Yet, some of these streams are now in excellent condition and are still incapable of supporting sustainable coho populations (Smith et al. 1997; Smith 2001; West 2002; SCWC 2005). In fact, the primary limiting factors to sustainable coho populations south of San Francisco are most closely related to the natural climate and geomorphology of the Santa Cruz Mountains, which predate and are less influenced by human land use activities. Frequent and severe floods and droughts are clearly the fundamental impediments to long-term coho survival, easily extirpating entire year-classes regardless of the effects of past human activities.

Additionally, decade-scale oscillations in the temperatures and productivity of the California Current help form a distinctly lethal combination for coho south of San Francisco.

Stream Habitat

First, stray colonizations south of San Francisco as hypothesized above were probably rare, low in number, and spotty in time and location. These factors alone make persistent colonization unpredictable and scanty (Mac Arthur and Wilson 1967). Next, the environmental stream conditions south of San Francisco are marginal, harsh, and extreme for coho salmon (Smith 1992, 1994; Anderson 1995; Smith 1996, 1998, 1999, 2001, 2002). The geology of the Santa Cruz Mountains is complex. Geologic materials mainly are mudstone, sandstone, and weathered granitic rocks and sediments. These are subject to ongoing episodes of erosion, landslides, and debris flows as a result of heavy rains, earthquakes, and ongoing tectonic uplift (Baker et al. 1998; Spittler 1998; SCWC 2004). Sediments delivered to streams from these materials have high percents of silts and sands. Such relatively fine material clogs the interstices of spawning gravels. It also slows the in-gravel flow of water and lowers the interstitial dissolved oxygen level. These conditions result in a lowered egg and alevin incubation survival compared to more favorable open gravels such as those found in Lagunitas Creek, just north of San Francisco (Bratovich and Kelley 1988). Fine materials also tend to compact the spawning gravels, making spawning redd digging by female coho salmon more difficult (Sandercock 1991). Shapovalov and Taft (1954) identified silting as the primary cause of egg loss in Waddell Creek.

Also, the latitude of the Santa Cruz Mountains results in summer stream temperatures generally warmer than those of more northern waters where persisting populations of coho salmon are found. Weitkamp et al. (1995) reported that average annual sunshine along the central California coast is greater than anywhere further north. Warmer water stimulates coho metabolism, placing greater pressure on available in-stream food resources (Bisson et al. 1988). Conversely, colder stream temperatures slow metabolism, producing more two-year-old smolts. Sandercock (1991:424) stated that "the occurrence of a high proportion of two-year-olds is much more common in the north." The incidence of two-year-old smolts in British Columbia and Alaska has been observed as high as 50–58.4% of outmigrating smolts (Sandercock 1991). Notably, Shapovalov and Taft (1954) found a zero percent frequency of two-year-old coho smolts in Waddell and Scotts creeks. The occurrence of two-year-old smolts alleviates the reproductive isolation of the three brood years and creates greater genetic variability by permitting spawning among fish of different year-classes. The significance of this should not be overlooked. Local coho salmon are especially affected by the harsh, marginal conditions south of San Francisco due in large part to their rigid three-year life history, with three distinct year-classes (as reported by Shapovalov and Taft 1954). As opposed to steelhead (that are indisputably native south of San Francisco), coho salmon do not have the capability of spawning over multiple years. Steelhead can remain at sea for a variable number of years and spawn multiple times during their lives or remain permanently in freshwater as rainbow trout. Thus, steelhead are much less vulnerable to stochastic events than are southern coho salmon.

Droughts lower stream flows and raise stream temperatures. Brown et al. (1994) and Brown and Moyle (1991) pointed out the severe effects that droughts have had on southern coho salmon populations. Even under normal, non-drought conditions, coastal streams south of San Francisco consistently lack flows sufficient during summer and fall to breach sand bars that block their mouths. For Scotts and Waddell creeks, stream blockage occurs during normal years and usually delays potential coho salmon migration until November or December (Shapovalov and Taft 1954; Sandercock 1991). Streig (Monterey Bay Salmon and Trout Project, pers. comm. 2005) stated that stream mouth blockages and late seasonal rains have been the main reasons coho salmon have been unable to establish persistent wild spawning populations in Scotts and Waddell creeks. During drought years the situation is exacerbated and sand bars can remain closed throughout the year. More intense drought conditions predated the last 100 years (Stine 1994; Woodhouse and Overpeck 1998; Jones et al. 1999; Benson et al. 2002; Weiss 2002). During prehistoric droughts, sand bars probably remained closed for multiple years, preventing any coho from spawning. Woodhouse and Overpeck (1998) identified a severe 20-year drought as recently as 1565, detected in paleoclimatic records from the California coast. These droughts may have closed the mouths of coastal streams south of San Francisco for many years. Closures lasting only three consecutive years would have extirpated a complete propagule colony of coho. Otherwise, smaller droughts, with many years in between, can eliminate single year-classes (which tend to remain vacant) until all three year-classes are gone. In addition, droughts can reduce stream flows well below critical levels necessary for sustaining any coho populations.

In annual reports, Smith (1992 to 2002) reported the combined harsh effects that droughts and floods have had on the coho salmon in Scotts and Waddell creeks. As background, Santa Cruz County has lower relative annual rainfall and higher relative peak storm events than counties to the north. Figure 3 shows that Marin County (directly to the north of San Francisco) is more likely than Santa Cruz County to receive more than one inch of rain in a single day from May through September. Alternatively, Santa Cruz County is significantly more likely to receive more than four inches of rain in a single day throughout the winter and spring (Figure 4), though Marin County receives the same or more average daily and monthly precipitation throughout the year as Santa Cruz County (Figures 5 and 6). All of these rainfall comparison differences are highly statistically significant (nonparametric sign-rank test). Thus, streams in Marin County are better supplied throughout the year and yet are not subject to the degree of precipitation extremes experienced in Santa Cruz County. The dynamic range of precipitation and thus stream flow in the Santa Cruz Mountains is even more discernable when compared to more northern prime coho salmon streams where coho salmon populations are stable.

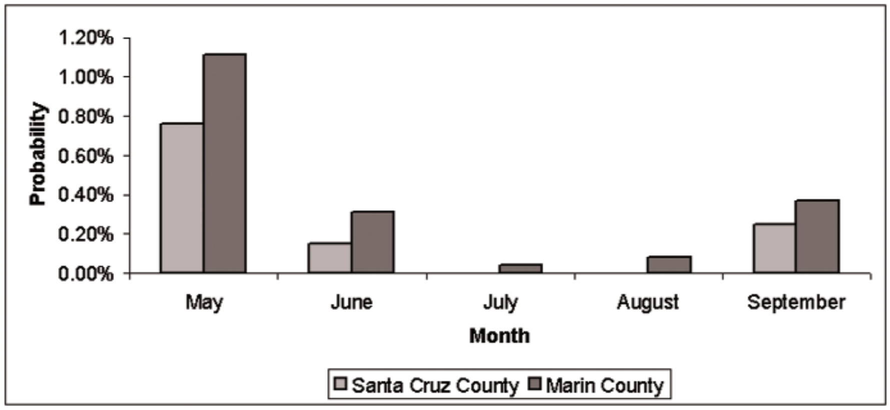


Figure 3. Probability of receiving more than 1 inch of precipitation in a single day for Santa Cruz and Marin counties from the end of spring to the beginning of fall. Precipitation probability was calculated using precipitation records for the Ben Lomond No. 4 station in Santa Cruz County (1937–2004) and the Kentfield station in Marin County (1931–2004). Both these stations represent the highest precipitation records available for their respective counties. Source: NOAA 2004a.

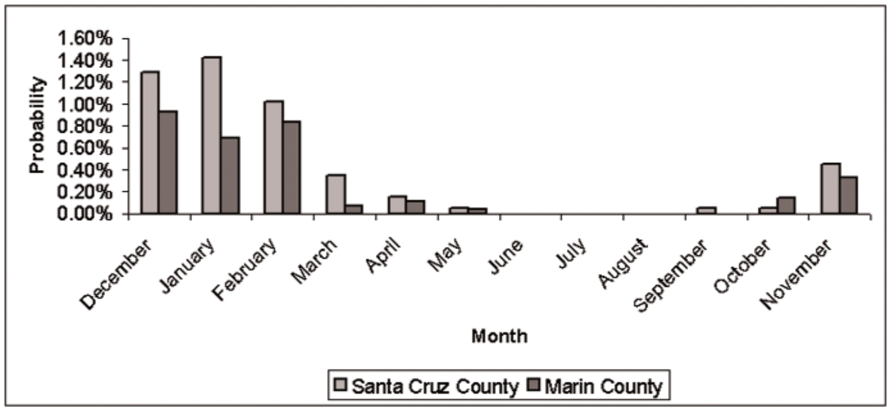


Figure 4. Probability of receiving more than 4 inches of precipitation in a single day for Santa Cruz and Marin counties. Precipitation probability was calculated using precipitation records for the Ben Lomond No. 4 station in Santa Cruz County (1937–2004) and the Kentfield station in Marin County (1931–2004). Both these stations represent the highest precipitation records for their respective counties. Source: NOAA 2004a.

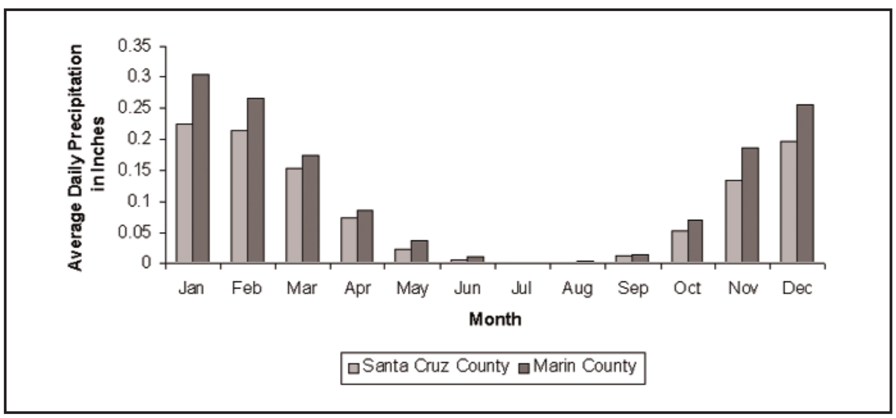


Figure 5. Average daily precipitation for Santa Cruz County and Marin County. Every record available for every station for each county was used. Source: NOAA 2004a.

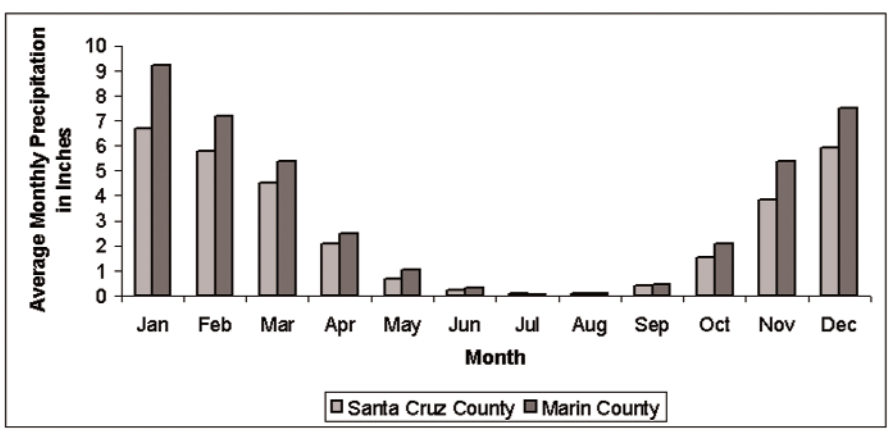


Figure 6. Average monthly precipitation for Santa Cruz County and Marin County. Every complete monthly record available for every station for each county was used. Months that were missing any daily records were excluded. Source: NOAA 2004a.

The combination of large storms and harsh periods of low rainfall south of San Francisco leads to minimal summer and fall stream flows, and flashier winter floods (Smith 1992, 1994, 1996; Baker et al. 1998; Smith 1998, 1999, 2001, 2002). High floods tend to wash out spawning gravel deposits, killing any incubating eggs and alevins. Anderson (1995) noted that Scotts and Waddell creeks tended to have highly mobile sediment bedloads. Floods can also destroy coho food production and decimate smolt production by overwhelming fingerlings (Sandercock 1991). Year-classes in coho-bearing streams south of San Francisco were nearly eliminated by drought-restricted access as recently as 1991 and floods weakened or decimated coho redds and overwintering juveniles in 1992, 1995, 1997, and 1998.

Sandercock (1991: 419) stated that:

> [c]oho streams with the best overwintering habitat were those with spring-fed ponds adjacent to the mainstream (Peterson 1980) or protected, slow flowing side channels that may only be wetted in winter (Narver 1978). In unstable coastal systems, coho production may be limited by the lack of side channels and small tributaries to provide protection against winter freshets.

Coastal streams of the Santa Cruz Mountains epitomize unstable coastal systems and discernibly lack adjacent spring-fed ponds and slow-flowing vernal side channels. Yet, they are subject to some of the largest storms on the West Coast.

Ocean Conditions

Kaczynski (1998) described the linked inland climate/California Current decade-scale relationship. He showed that when climate conditions inland are warm and dry, the California Current is warm with poor biological productivity and increased predators not normally encountered by juvenile coho salmon. The warm California Current conditions result in significantly lowered coho salmon marine survival, as low as 0.5 to 1% in the early to mid 1990-era (Kaczynski 1998; Welch et al. 2000). Kaczynski (1994), using the net replacement method (Birch 1948; Caughley 1967), demonstrated that at least 2.7% marine survival is needed for coho salmon to maintain ongoing population persistence assuming 3% freshwater survival egg to smolt and 1,250 female eggs per female. Freshwater survival of 3% was the average found in 5 streams studied in western Oregon and Washington and 2,500 eggs per female (1,250 female eggs per female assuming equal sex ratio) is the Oregon coast average (ODFW 1982). Sandercock (1991) reported a 1 to 2% egg to smolt survival in British Columbia and a cline in fecundity from north to south: larger females with more eggs to the north and smaller females with fewer eggs to the south. Given the harsh freshwater conditions found in Santa Cruz County streams, a 1% freshwater survival from egg to smolt is not unreasonable. Survival could easily be lower per the conditions described by Smith (1992, 1994, 1996, 1998, 1999, 2001, 2002). Shapovalov and Taft (1954) gave a formula to calculate the expected coho eggs per females at various sizes. Using an observed average length of 63.8 centimeters for female coho in Waddell Creek, the average eggs per female would be 2,336, consistent with the trend described by Sandercock (1991). Using 1,168 female eggs per female (assuming equal male/female ratio), 1% freshwater survival would require at least an 8.6% marine survival for year-class persistence (a one-to-one net replacement rate), while 0.5% freshwater survival would require 17.1% marine survival to maintain persistence (a value never seen). The median coho salmon marine survival estimate for 1960 to 1975, considered a cool and productive period, was 7.2%. The range was 4.4% to 12.7% (Kaczynski 1998). These data indicate that during a cool, productive California Current cycle, occasional, stray coho salmon propagules south of San Francisco would have a net replacement rate of less than one (declining) in over half the years at 1% freshwater survival. They would have severe numerical declines when freshwater survival was only 0.5%. These data also help explain the progressive depletion of coho year-classes observed by Shapovalov and Taft (1954), following heavy hatchery plants in the years immediately before their study. The low freshwater survival rates caused by harsh freshwater conditions could not be overcome by high enough marine survival rates. So, the Waddell Creek coho salmon population went steadily downwards, and the same would happen to any stray local propagule year-class. Local long-term population persistence would be problematic to very unlikely even during good, cool California Current conditions.

The combination of periodic, decade-scale linked warm and dry inland climate and warm unproductive California Current conditions, plus the hydrologic tendency to have seasonal floods, would be expected to augment stress to any occasional coho stray year-class (temporarily) occupying a local stream. Under such stressful conditions, persistence would be extremely improbable. Using 1,168 female eggs per female, a 1% marine survival rate (as seen in warm, unproductive California Current cycles) coupled to a 1% freshwater survival rate would result in a net replacement rate of 0.117 (declining by about 88% per year-class cycle). A 0.5% marine survival rate coupled with a 0.5% freshwater survival rate would result in a net replacement rate of 0.029 (declining by about 97% per year-class cycle). Natural extinction would occur in these situations fairly quickly as a replacement rate greater than or equal to one is necessary for persistence. A comparison to coho salmon survival and productivity in the Oregon Production Index Area, where coho salmon are persisting and data are available, is helpful. Using 3% average freshwater survival (based on 5 studies in Western Oregon and Washington; ODFW 1982), and 1,250 female eggs per female (ODFW 1982) with the net replacement rate method (Birch 1948), three smolt years follow with their estimated marine survivals (Kaczynski 1998) and calculated net replacement rates:

Smolt Year	Marine Survival (%)	Net Replacement Rate
1970	8.4	3.15 (growing year class, by 315%)
1980	2.7	1.01 (stable year class)
1996	0.7	0.26 (severely declining year class, by 74%)

DISCUSSION

Once researchers introduce aberrations into the literature of public or scientific discourse, peers are free to cite it in subsequent publications, strengthening the appearance of hard fact with each iteration. Table 3 and Figure 7 trace the sources and paths of the misinformation in the current literature regarding the historical distribution of coho salmon south of San Francisco, which has obfuscated the scientific record of coho salmon in these streams. The sources listed in Table 3 and Figure 7 are the basis of the currently prevailing assumption that coho are native and were once naturally abundant south of San Francisco. The only potential evidence we found supporting a historical coho presence is strikingly absent from these sources, underscoring how easy it is to build upon others' errors.

Our hypotheses can be evaluated based upon the overall weight of the evidence (Table 4). Given the frequency of the periodic marine temperature and productivity oscillations, the primary freshwater obstacles to coho survival (droughts, floods, geomorphology), and the tendency of these stochastic events to undermine every potential coho stream within the Santa Cruz Mountains, it is unlikely there were persisting populations in any one stream capable of maintaining an enduring southern metapopulation (first hypothesis). Straying from northern metapopulations may have subsequently established new ephemeral colonies but would have had no effect on stochastic extirpation events south of San Francisco. Whether these hypothetical native coho populations were extirpated prior to any surveys is unknown (second hypothesis). If such was the case, all coho south of San Francisco today are thus the result of anthropogenic introductions. The third hypothesis that coho were repeatedly missed prior to 1909 by the leading ichthyologists of the time,

Table 3. Sources cited directly or indirectly in the "Recovery Strategy for California Coho Salmon" (CDFG 2004) regarding the native origin of coho salmon south of San Francisco. "False Citations" are instances where the source does not support the cited assertion concerning the native origin of coho south of San Francisco. "Citations of Erroneous Information" are indirectly false citations, or instances where the source cited appears to substantiate the assertion concerning the native origin of coho south of San Francisco; yet, when traced to its origin, the claim has no apparent basis. No citations of suppor evidence were found.

Document	Statements Made With No Reference Cited	Personal Observations or Communications	False Citations	Citations of Erroneous Information
Recovery Strategy for California Coho Salmon (CDFG 2004)	X		X	
Status Review of California Coho Salmon North of San Francisco (CDFG 2002)		X	X	
A Status Review of Coho Salmon (*Oncorhynchus kisutch*) in California South of San Francisco Bay (Anderson 1995)	X	X	X	
Historical Decline and Current Status of Coho Salmon in California (Brown et al. 1994)	X	X		
Status Review of Coho Salmon Populations in Scotts and Waddell Creeks, Santa Cruz County, California (Bryant 1994)	X	X	X	X
Petition to List Coho Salmon South of San Francisco Bay as a Threatened Species (Hope 1993)	X	X	X	X
History of Fish Cultural Activities in Santa Cruz County with Reference to Scotts and Waddell Creeks (Streig 1991)	X	X		
Status of Coho Salmon in California (Brown and Moyle 1991)		X	X	
Distribution of Coho Salmon in California (Hassler et al. 1991)	X		X	
Distribution of Coho Salmon in California (Hassler et al. 1988)	X		X	
Anadromous Salmonid Genetic Resources (Berger 1982)	X		X	
The Distribution of Six Selected Species from the Genera *Oncorhynchus, Salmo,* and *Salvelinus* in California (Lucoff 1980)		X		
Hereditary and Environmental Factors Affecting Certain Salmonid Populations (Ricker 1972)		X		

Figure 7. The false citations (dashed lines) and citations of erroneous information (solid lines) used to substantiate the hypothesis that coho are native south of San Francisco. The circles represent literature of current public or scientific discourse that contends the historical southern extent of the coho salmon spawning range is south of San Francisco. The arrows indicate the material referenced to substantiate these claims. For more details see Table 3.

The California Department of Fish and Game (2002; 2004) cite Snyder (1931) and Fry (1973). Snyder (1931) does not discuss the southern extent of coho salmon, while Fry (1973) only describes the distribution of coho salmon in 1973, not historically. The California Department of Fish and Game (2002) also cite Sandercock (1991) for a map they title "Native range of coho salmon" whereas Sandercock's (1991, Figure 1, pg. 398) caption reads, "Figure 1 Coastal and spawning distribution of coho salmon." He states, "Endemic populations of coho are found throughout the North Pacific basin (Figure 1)…" The resolution and scale of the original map is such that the southern range boundary is unclear in detail, but it appears to end at San Francisco Bay. Further, Sandercock (1991) gives no source, reference, nor citation for this statement and he does not discuss the historical distribution of coho.

Brown et al. (1994) cite Snyder (1908). Snyder (1908) does not concern anything south of the Sacramento River and makes no mention of any fish anywhere south of San Francisco. It is probable Brown et al. (1994) meant to cite Snyder (1914), however the observations of coho in Snyder (1914) postdated the return of hatchery introduced coho and do not indicate a native run.

Bryant (1994) changes Streig's words, giving the false impressions that the Scotts Creek egg-taking station was established in 1905 to collect coho eggs, and that it was the goal to produce 3 million coho eggs. Neither is the case, which is evident in several California Fish and Game Commission Biennial Reports (Van Sicklen et al. 1910; Newbert et al. 1913; Newbert et al. 1918, 1923)

Hope (1993) cites Waples (1991). Waples (1991) does not comment on the coho south of San Francisco.

Brown and Moyle (1991) cite only Shapovalov and Taft (1954) and presence/absence data since 1950. Shapovalov and Taft (1954) do not discuss the native origin of coho south of San Francisco.

Streig (1991) cites only Shapovalov and Taft (1954). Shapovalov and Taft (1954) do not discuss the native origin of coho south of San Francisco.

This document is a geography master's thesis written by Lucoff (1980) at California State University Hayward. He avers that Hallock ("1877, pp. 976, 756-57") mentions silver salmon fishing in the Santa Maria River in Santa Barbara County and cites this as his source for a map showing the distribution of coho in 1900. Hallock (1877) does not contain a page 756 or 757. Furthermore, Hallock (1877) does not mention silver salmon fishing nor the Santa Maria River. Hallock does state the following: "Their [all known varieties of Pacific salmon] range is from Sacramento northward…" (Hallock 1877:365). Lucoff's map also shows coho as far south as the Santa Ynez River, for which he has no source, reference, citation, or other justification.

Ricker (1972) cites Shapovalov and Taft (1954). Shapovalov and Taft (1954) do not discuss the native origin of coho south of San Francisco.

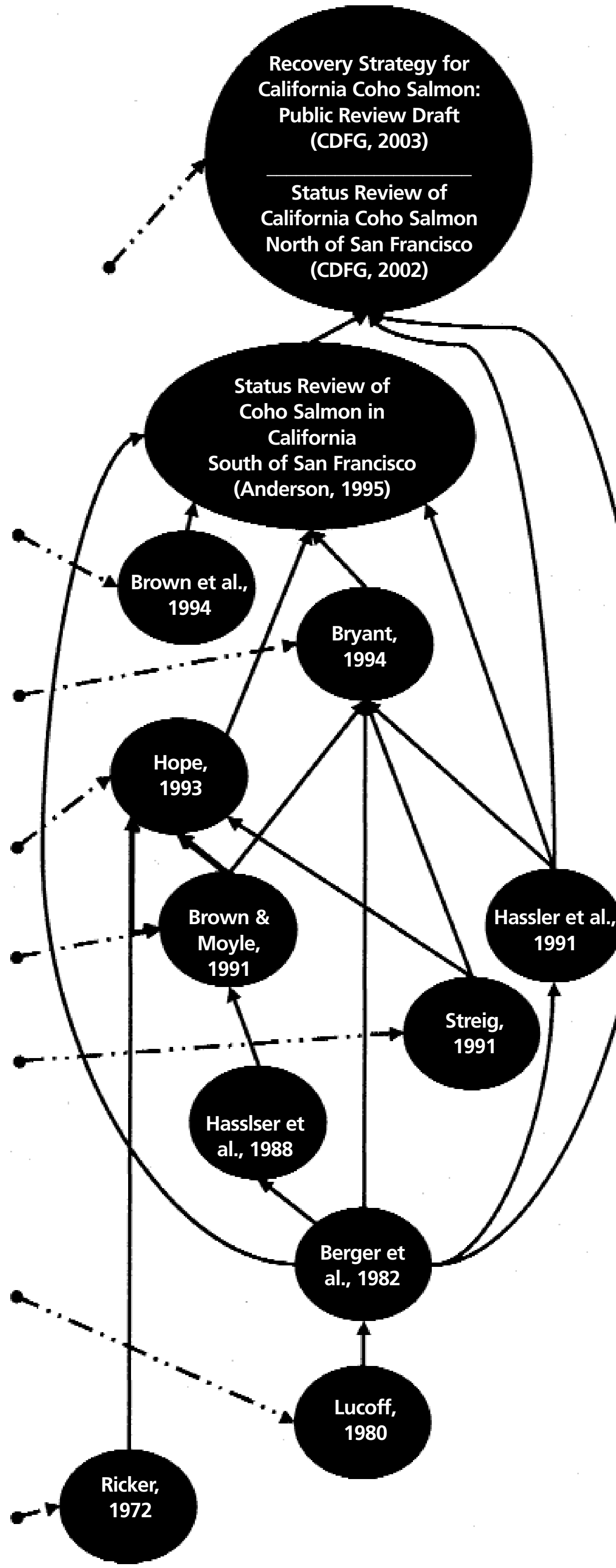


Table 4. Sources supporting the historical presence or absence of coho salmon in coastal streams south of San Francisco prior to documented hatchery introductions. Redding et al. (1872) can be interpreted either way. Auxiliary evidence and logical reasoning supporting absence was not included.

Presence		Absence	
Source	**Scope**	**Source**	**Scope**
Redding et al. 1872	Pescadero and San Gregorio Creeks	Redding et al. 1872	Pescadero and San Gregorio Creeks
California Academy of Sciences 1895a, b, No Date-a, b	Gazos, Waddell, Scotts, and San Vicente Creeks	Jordan and Gilbert 1876–1919	San Mateo County and Santa Cruz County
		Jordan et al. 1882	San Mateo County and Santa Cruz County
		Jordan 1892a, b, 1894, 1904a, b, 1907	San Mateo County and Santa Cruz County
		Jordan and Evermann 1896, 1902, 1905	San Mateo County and Santa Cruz County
		Mountain Echo December 16, 1905:3	Santa Cruz County
		The Mountain Echo March 24, 1906a:3	Santa Cruz County
		Welch 1907	Santa Cruz County
		Gobalet et al. 2004*	San Mateo County and Santa Cruz County

*While Gobalet et al. 2004 results support absence, their conclusions rely instead on Captain Wakeman (Skinner 1962), the California Academy of Sciences specimens (1895a, b, No Date-a, b), the inherent equivocal nature of archaeological evidence, and the prevailing but unsubstantiated conclusions of other authors (Brown et al. 1994; Behnke and Tomelleri 2002, P. B. Moyle, pers. comm. as cited in Gobalet et al. 2004) that coho are native south of San Francisco.

hatchery personnel operating fish traps on two of the streams most likely to harbor coho, and the general public including countless avid angling enthusiasts, is improbable and does not follow from the overall weight of the evidence. We find the overall weight of evidence best supports our fourth hypothesis that coho salmon sustainable populations were historically distributed only as far south as San Francisco, with potential temporary year-class colonies occasionally occurring further south from strays in some coastal streams. In addition to the overall weight of the historically pertinent information, the best scientific information supports the conclusion that the climatic and geomorphological conditions south of San Francisco do not favor the existence of a viable indigenous coho population. Natural environmental limitations are so harsh that occasional, small, localized, single year-class propagules of coho salmon could not naturally persist for long. Hatchery-derived populations (since 1906) have basically suffered the same fate and will continue to do so regardless of habitat restoration efforts in a few of the degraded streams. The best available scientific information indicates that a strictly wild-spawning coho salmon population would not persist for any extended time period in the region south of San Francisco in the absence of hatchery support.

This assessment of the southern range boundary opened a number of questions on what a species range boundary really is. Federal and state Endangered Species Acts need discrete range boundaries for practical management purposes and for defining critical habitats where applicable. Ecologically speaking, these requirements produce artificial boundaries that assume static conditions. Range boundaries in nature are dynamic over time and space. They change naturally in response to climate cycles and events, geologic processes and events, and interspecific interactions. Jordan (1887) reported Chinook salmon in Pescadero Creek and described a Chinook spring run in the Carmel River. Are these isolated presence records sufficient evidence to extend the Chinook range southward? What time scale do we use to define a range boundary? The natural ranges of salmon since (and before) the Pleistocene have varied considerably (McIntyre 1981; Waples et al. 2004). What is the timeframe for estimating natural abundances for recovery goals? The concept of recovery is meaningless if natural abundance within a relevant timeframe cannot be demonstrated.

How do we treat dispersal propagules of a species and ephemeral year-class populations? Pink salmon (*O. gorbuscha*) adults are found during some spawner surveys in Oregon coastal streams. The Oregon Department of Fish and Wildlife treats these adults as strays, not native fish. No ongoing populations of pink salmon have been found there (T. Nickelsen, Oregon Department of Fish and Wildlife, pers. comm. 1993). Adult pink and chum salmon have been found in the Klamath River but CDFG treated them as strays and not native populations (CH2M Hill 1985). Stray pink and chum salmon were found in the San Lorenzo River in 1916 (Scofield 1916). Scofield stated that this was not the first time that such occasional strays had been noted in the San Lorenzo and that this "… was the most southerly point from which it [chum] has been recovered." Should this be the basis for defining the San Lorenzo River as the southern range boundary of the distribution of chum salmon under the Endangered Species Act? In our southern coho assessment, we went back in time as far as we were able, and we concluded that the self-perpetuating criterion was critical. Strays are expected but straying by itself should not define a range boundary in this context. If the propagule spawnings do not result in ongoing populations, they do not define the range of that species. Prior to the hatchery efforts beginning in 1906, we could find no evidence of coho salmon having persisting populations south of San Francisco.

CONCLUSIONS

Taken together, the archeological evidence, the harsh local environmental conditions, the early presence/absence scientific literature, the later presence/absence literature, the soft literature, the long history of nonnative coho salmon hatchery plants, the ongoing hatchery programs, the ongoing genetic and infusion straying effects, and the consideration of marine and freshwater survival rates, leads us to conclude that the presence of persistent populations of coho salmon south of San Francisco is improbable. The historical and tenuous present coho salmon populations in Santa Cruz County apparently were and are nonnative populations.

COURTESY ROBERT BRIGGS

Dr. and Mrs. David Starr Jordan visit Waddell Creek in 1920.

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Routine Use of Sterile Fish in Salmonid Sport Fisheries: Are We There Yet?

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ABSTRACT: Since 1997, Idaho Department of Fish and Game hatchery and research personnel have worked cooperatively to develop a sterile trout program with the primary goals of protecting the genetic integrity of native stocks while continuing to supply hatchery-reared trout for harvest-oriented anglers. Results of recent field evaluations of sterile rainbow trout (*Oncorhynchus mykiss*) demonstrate that they provide recreational fisheries of equal or superior quality to normal diploid fish when stocked as catchables in streams or as fingerlings in productive lentic systems. Our preliminary evaluations suggest that use of sterile trout in high mountain lakes may require stocking adjustments or may eventually prove problematic because of lower survival rates. Sterile trout eggs can be readily purchased from commercial sources or produced from agency broodstocks with nominal equipment and manpower costs. To gain a better understanding of sterile fish use by other agencies, we conducted a U.S. state phone survey during 2005, and posed questions to fisheries administrators regarding their stocking practices. Officials from 10 states indicated that they had ongoing programs for sterilizing hatchery salmonids. Eight of these programs were located in the western United States, while only two occurred east of the Mississippi River. The presence of native species either listed under the Endangered Species Act or petitioned to be listed has greatly influenced agency interest in sterile fish programs. Regardless of native species status, we believe that expansion of sterile hatchery trout programs can improve conservation and management programs in other states. Despite our obvious enthusiasm for use of sterile trout in recreational fisheries, they are not a panacea, and we call for additional evaluations with normal diploid trout in states developing such programs.

INTRODUCTION

The widespread hybridization of native salmonid stocks due to introduction of nonnative species or strains is well documented (Allendorf et al. 1980; Campton and Johnston 1985; Hindar et al. 1991). Despite concerns for genetic impacts, hatchery trout stocking continues to play a significant role in the management of many trout fisheries (Hartzler 1988; Wiley et al. 1993; Van Vooren 1995). The continued stocking of hatchery trout in streams reflects the dual mission of many state fisheries agencies: in Idaho as in many other states, resource managers are legislatively charged with perpetuating and protecting native species, while also providing harvestable surpluses for the public (Dillon et al. 2000b).

Use of sterile trout in hatchery programs potentially could minimize genetic interactions with native stocks. Since the early 1980s, techniques for inducing triploidy in salmonids have been frequently studied (see review by Benfey 1999). Techniques include subjecting recently- fertilized eggs to either a pressure or heat shock (Thorgaard and Jazwin 1981; Chourrout 1984). During meiosis, extrusion of the second polar body is blocked, and the fertilized egg thus possesses three sets of chromosomes. The third set of chromosomes renders the fish functionally sterile. Adult-size triploid females never produce fully developed eggs (Thorgaard 1983; Lincoln and Scott 1984). Triploid males are capable of producing only dilute, infertile milt. Despite these reproductive abnormalities, triploid males develop secondary sex characteristics and exhibit courtship and spawning behaviors, whereas triploid females do not (Warrillow et al. 1997).

The commercial aquaculture industry provided much of the impetus for developing production techniques for triploid salmonids. Despite slightly higher rates of mortality during early rearing stages (Happe et al. 1988; Guo et al. 1990) and higher incidences of deformities (Sutterlin et al. 1987), hatchery performance of triploid trout, especially females, may be better than diploids. For example, triploid fish often have higher feed conversion rates than diploid fish (Wolters et al. 1982, 1991). Additionally, since female triploids allocate less energy into egg development, triploid females may grow more quickly than diploids after the onset of sexual maturation in diploids (Lincoln and Bye 1987; Sheehan et al. 1999). Furthermore, triploid females do not suffer declines in flesh quality or increased mortality rates associated with spawning; thus, they yield a more consistent product for consumers. Such observations stimulated the development of techniques for producing all-female triploid lines (Chourrout and Quillet 1982).

During 1997, the Idaho Department of Fish and Game (IDFG) began a multi-year research program evaluating the possibility of converting its entire resident rainbow trout (*Oncorhynchus mykiss*) hatchery program to production of sterile fish for stocking. Despite numerous comments in the primary literature suggesting the merits of sterile hatchery trout to minimize introgression risks and the potential for better in-hatchery performance, we could find no published literature evaluating use of triploid hatchery trout in stream sport fisheries prior to the mid-1990s. Moreover, only two studies described their use in lake fisheries to protect wild-stock integrity (Rohrer and Thorgaard 1986; Brock et al. 1994). Before implementing a large-scale sterile trout stocking program, studies evaluating the performance of triploid trout in actual fisheries were necessary. The primary management goal of this research program was to minimize genetic risks to native rainbow trout and cutthroat trout (*O. clarki bouvieri, lewisi,* and *utah*) stocks in Idaho streams from hatchery trout while continuing to provide harvest opportunities. Triploid trout should also provide fisheries similar in quality to diploid trout and at a reasonable cost, if they are to be a useful management tool.

In this article, we first summarize results of field evaluations that assessed the performance of sterile trout in Idaho recreational fisheries. We then provide suggestions and techniques for development of production-level sterilization programs. Finally, we report on results of a 2005 phone survey of U.S. states with salmonid hatchery programs. The survey was conducted to assess the relative size of state hatchery programs, to characterize wild trout management perspectives (where appropriate), and to assess geographic trends in the use of sterile hatchery trout in recreational fisheries.

FIELD RESEARCH METHODS AND RESULTS

Stream Evaluation: During 1997, a total of 10,800 mixed-sex triploid and 10,800 mixed-sex diploid rainbow trout catchables (265 mm) were jaw-tagged and stocked into 18 streams located throughout Idaho (Dillon et al. 2000a). Relative return of angler-caught fish was used as the primary evaluation metric in a paired t-test. Results indicated that triploid trout were harvested at virtually the same frequency (n = 931) as diploid trout (n = 918), and overall returns were not statistically different (P=0.80). In addition, the timing of angler returns was virtually identical (Figure 1). Similarity in returns between groups was viewed as a positive result since the objective of the stream portion of the triploid trout program was to provide the same level of angler harvest as was provided by past stockings of normal diploid rainbow trout.

Reservoir Evaluation: Equal numbers of fingerling all-female triploid and all-female diploid rainbow trout were marked with different grit-dye colors and stocked into two Idaho reservoirs managed with special regulations (Teuscher et al. 2003). Gill netting and shoreline electrofishing were used to monitor relative growth and survival over a subsequent 4-year period. Growth rates and maximum sizes were similar for triploids and diploids (Table 1). The final catch ratios (triploid:diploid) for all years combined were 1.4:1 and 1.9:1 in Treasureton and Daniels reservoirs, respectively (Figure 2). Results indicated that triploid fingerling rainbow trout in productive lentic environments may not demonstrate a consistent growth advantage over diploid trout; however, triploids may have higher long-term survival rates, extending the period that a specific cohort is susceptible to anglers. Though angler harvest was not evaluated in this study, improved survival likely translates to better angler returns and reduced cost per fish creeled.

High Mountain Lake Evaluation: To evaluate relative survival and growth of sterile trout in less-productive high moun-

Figure 1. Cumulative first-year returns-to-creel over time (100 d post-stocking) for triploid and diploid hatchery rainbow trout in 18 streams combined (adapted from Dillon et al. 2000a).

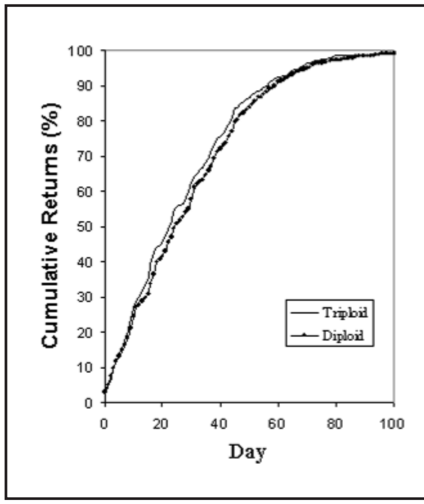


Table 1. Mean length and weight statistics for triploid and diploid rainbow trout sampled in the Treasureton and Daniels reservoirs, Idaho. Values in parenthesis = SE. The df for *t*-tests were the same for the length and weight comparisons (adapted from Teuscher et al. 2003).

		Length (mm)		*t*-test statistics			Weight (g)		*t*-test statistics	
Reservoir	Month	3n	2n	T	df	*P*	3n	2n	t	*P*
Treasureton	5	157	150		38	36				
	13	266 (5)	267 (4)	-0.14	40	0.89	243 (14)	245 (9)	-0.16	0.87
	24	398 (4)	401 (4)	0.80	45	0.43	708 (22)	812 (28)	2.88	0.01
	29	446 (3)	448 (3)	0.44	47	0.67	904 (16)	1,005 (28)	3.17	0.00
	37	498 (6)	488 (7)	-1.04	26	0.31	1,260 (41)	1,376 (81)	1.44	0.16
	41	496 (4)	483 (7)	-1.65	40	0.11	1,134 (33)	1,170 (54)	0.59	0.56
	47	528 (8)	501 (16)	-1.55	13	0.15	1,469 (66)	1,550 (122)	0.61	0.55
	51	535	465		1,400	800				
Daniels	5	157	150		38	36				
	11	187 (6)	183 (5)	0.18	33	0.86	70 (6)	68 (5)	0.37	0.71
	24	380 (39)	429 (30)	-1.01	2	0.42	825 (125)	1,000 (300)	-0.54	0.64
	29	475 (5)	501 (7)	3.08	25	0.00	1,166 (52)	1,428 (85)	2.70	0.01
	37	521 (9)	508 (18)	0.66	16	0.52	1,398 (67)	1,293 (139)	-0.73	0.48
	41	527 (9)	527 (8)	-0.03	13	0.97	1,346 (80)	1,433 (115)	0.64	0.53
	47	510 (9)			1,117 (104)					

tain lake environments, IDFG has stocked paired groups of mixed-sex triploid and diploid fingerling rainbow trout in a total of 35 high lakes. Although this effort is not yet complete, results from a pilot study in 4 lakes (combined gill net and angling return ratio equaled 1 triploid : 2.3 diploids) and first-year findings from 16 lakes in the larger evaluation (1 triploid : 1.9 diploids) suggest that triploid rainbow trout may not survive and grow as well as diploid rainbow trout in high elevation lakes (Kozfkay 2003, 2004). While these results are preliminary, it is not unreasonable to suggest that use of sterile trout in high mountain lakes may require stocking adjustments or perhaps may eventually prove to be problematic. Our field evaluations should be complete within 3 years.

Treatment Development: Since 1997, a series of experiments have been performed at IDFG hatchery facilities to develop treatments for production of sterile trout. Starting points for treatments were identified from similar studies in the primary literature. Key variables evaluated for heat-shock treatments included water temperature, the number of minutes after fertilization before eggs were immersed in a heat bath, and the length of time eggs remained in the heated water. We initially sought to determine whether published treatments could be improved for our broodstock strains and ambient hatchery water temperatures. Our early, experimental, heat-shocking units were inexpensive 51 L insulated coolers. These coolers were fitted with inlet and outlet hoses and attached to a recirculating heat pump (PolyScience Inc., Model 210). The total cost of an entire treatment unit was US $650.

A total of 38 heat-shock treatments were tested on fertilized eggs from 2 rainbow trout broodstocks. A treatment of 26° C applied 20 minutes after fertilization for 20 minutes provided the highest survival and triploidy induction rates. This is the same treatment developed earlier by Alaska Department of Fish and Game (Habicht et al. 1994) and is similar to a treatment cited in the literature as being effective (Chourrout and Quillet 1982; Diaz et al. 1993). Treatment procedures may need to be adjusted if ambient hatchery water temperature differ substantially from the 11.4º C used during our experiments. In addition to rainbow trout treatments, another 7, 9, 12, and 6 treatments were tested for cutthroat trout, brook trout (*Salvelinus fontinalis*), lake trout (*S. namaycush*), and kokanee salmon (*O. nerka*), respectively. Triploidy induction and resultant sterility rates for the most useful treatments for these species have ranged between 91 and 100%; typically over 98% (Table 2; Kozfkay 2002, 2003, 2004).

LARGE-SCALE TRIPLOID TROUT PRODUCTION

Based on the field results and extensive treatment experiments described above, IDFG elected to move forward with large-scale triploid production for our two in-state rainbow trout broodstocks. A pro-

Figure 2. Relative catch as an index of survival (gillnet and electrofishing catch combined) for sterile (triploid) and control (diploid) rainbow trout in Treasureton and Daniels reservoirs, Idaho. The dotted line represents equal catch between both groups (1:1 ratio). More sterile fish were caught than control fish in all but 10 of 11 sampling events (adapted from Teuscher et al. 2003).

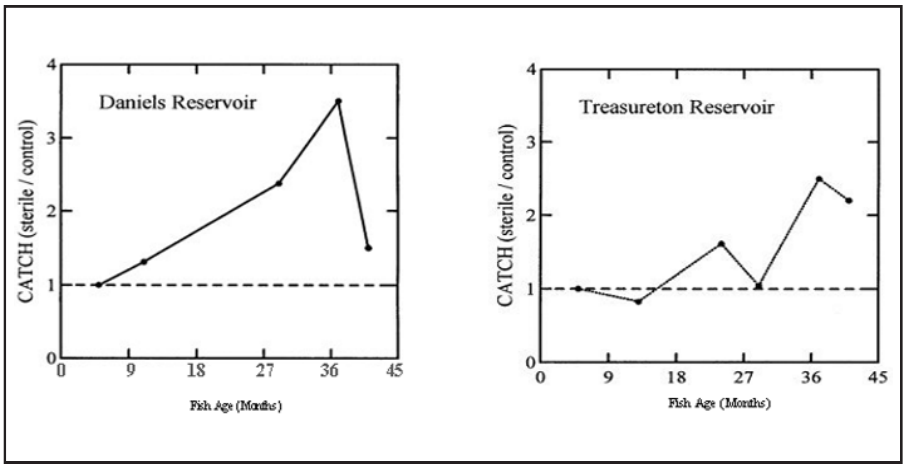


Table 2. Results of sterilization experiments performed on brook trout, Henrys Lake hybrid trout (male rainbow trout crossed with female Yellowstone cutthroat trout), rainbow trout, westslope cutthroat trout, lake trout, and kokanee salmon at IDFG hatchery facilities from 2001–2004. The eyed egg stage is abbreviated as EE in column headings.

Trout species/strain	Treatment type	Intensity	MAF[1]	Duration (min)	Ambient hatchery water temperature (°C)	Treatment survival to EE(%)	Control survival to EE(%)	Triploidy induction (%)
Brook	heat	29.4 °C	18.0	7	7.5	62	89	100
	pressure	9,500 psi	40.0	5		59	72	100
Henrys Lake hybrids	heat	28.0°C	15.0	20	7.5	29	60	100
	pressure	10,000 psi	40.0	5		43	39	100
Rainbow	heat	26.0°C	20.0	20	11.4	91	95	96
	pressure	9,500 psi	33.0	5		90	95	100
Westslope cutthroat	heat	28.0 °C	10.0	10	11.4	41	54	96
	pressure	9,500 psi	26.3	5		52	54	99
Lake trout	heat	29.4 °C	18.0	7	9.3	40	65	63
	pressure	9,500 psi	32.0	5		53	62	100
Kokanee	heat	27.0°C	20.0	20	9.0	49	77	98
	pressure	9,500 psi	17.2	5	9.5	54	79	100

[1] Minutes after fertilization

duction-sized heat bath was built by IDFG employees for use at the Hayspur rainbow trout broodstock facility. The interior dimensions of the fiberglass hot water bath were 85 x 123 x 11 cm, yielding a volume of 0.1 m^3. Two heat pumps (PolyScience Inc., Model 210) and a recirculating pump (March Mfg. Inc., Model AC-3C-MD) were used to ensure that water temperatures remained stable. This unit cost approximately US $2,500 and allows heat-shock treatment of 500,000 eggs/d with a 4-person crew. Sterilization of production quantities of rainbow trout eggs in Idaho was begun in 2000 and increased to a maximum annual production of 16 million eggs by 2001. Based on a monitoring program that uses a stratified random sampling strategy and flow cytometric evaluation of DNA content, the mean triploidy induction rate for production-level rainbow trout in Idaho has averaged 96.2% from 2001 to 2005 (Doug Burton, IDFG, unpublished data).

In 2003, IDFG acquired a hydrostatic pressure chamber suitable for production-level sterilization efforts that is providing better results (higher and more consistent triploidy induction rates), especially for Henrys lake hybrids (*O. mykiss* x *O clarki bouvieri*), lake trout, and brook trout, for which 100% sterility treatments have been achieved (Table 2; Kozfkay 2003; Kozfkay et al. 2005). The hydraulic pressure chamber, Model HPC™, used for these efforts was built by TRC Hydraulics Inc., Dieppe, New Brunswick, Canada, and costs approximately US $15,000. Since 2002, all hatchery rainbow trout used in the resident fish-stocking program in Idaho have been treated with heat or pressure to induce triploidy.

U.S. NATIONWIDE PHONE SURVEY

We used a telephone survey to pose a series of nine questions (Appendix 1) to fisheries administrators or hatchery supervisors for all 50 U.S. states. The primary purpose of these questions was to gauge the relative size of resident trout stocking programs, assess use of sterile fish, and gain a better understanding of how states acquire eggs for their trout stocking programs.

A total of 46 out of 50 states had hatchery stocking programs for salmonids (Table 3), the exceptions being Alabama, Mississippi, Florida, and Louisiana. Only 1 of these 46 states, Washington, indicated that they had a policy not to stock hatchery trout in streams. In the remaining 45 states, a total of 52.6 million hatchery trout were stocked in streams, yielding an average of 1.2 million trout stocked in streams per state, with a minimum of 3,000 (North Dakota) and maximum of 5.5 million (Michigan). Overall, the majority of fish stocked were rainbow trout (65%), followed by brown trout (18%), and brook trout (10%). The remaining 7% was composed of 11 other species.

Ten states indicated that they had ongoing programs for sterilizing hatchery-reared salmonids. The majority of these, eight, were located in the western United States; and only two occurred east of the Mississippi River (Vermont and North Carolina; Figure 3). All respondents with a sterile fish program indicated that the primary reason for their efforts was to conserve the genetic integrity of native stocks (Appendix 1). Two states indicated that secondary reasons were important also, including potential for increased growth (Nevada) and reduction of negative consequences associated with sexual maturation, such as reduced somatic growth and higher mortality rates (North Carolina). Three states indicated that their programs were functioning at the production level, while they continued to research this topic. Heat was the predominant technique used for sterilizing salmonids (6 states). Only one state (California) indicated that they used pressure exclusively, while three states used both heat and pressure shocking techniques.

For the 35 remaining states that do not have ongoing programs for sterilizing hatchery salmonids and stock streams with trout, we asked an additional question, "How do they manage around potential genetic conflicts between hatchery stocking and wild trout management?" Responses included: they had no native or wild populations in state (14 states), they used locally adapted broodstocks (3 states), they assumed negligible effects (6 states), they avoided stocking on wild populations (15 states), they stocked hatchery trout only below barriers (1 state), and that their hatchery-produced trout added few recruits to populations (1 state).

Of the 46 states with resident hatchery trout programs, 34 states indicated that they maintained their own broodstocks. Average production was 7.1 million trout eggs per year with a minimum of 200,000 eggs produced per year in Rhode Island to a maximum of 35 million eggs produced per year in Washington. State hatchery trout programs also received eggs from a variety of other sources including from federal hatcheries (10 states), bartered for eggs from other states (9 states), or purchased eggs from commercial suppliers (13 states).

Twelve states indicated that they have native salmonid stocks that are influenced by the Endangered Species Act (ESA), either listed as threatened, endangered, or currently being petitioned for listing. Maine was the only state east of the Mississippi that possessed a listed species of salmonid, Atlantic salmon (*Salmo salar*; Figure 3). The highest number of ESA-listed or petitioned species was in California (10), followed by Idaho, Oregon, and Washington that possessed 8 species each. Five states possessed ESA petitioned or listed stocks and did not have sterile fish programs.

DISCUSSION

Hybridization between native and hatchery-produced salmonids is a serious threat to the long-term persistence and genetic integrity of native stocks (Allendorf and Leary 1988), but public support and demand for stocking remains high. We believe that use of sterile trout in hatchery programs greatly reduces the risks associated with intra- and inter-specific hybridization, while adequately meeting public demands for harvest-oriented fisheries. We suggest that such programs could benefit many other states with similar mandates to protect native species and also provide harvest opportunities for anglers.

We acknowledge that some biologists may disagree with our observation that use of heat- or pressure-shocked fish is a viable solution to reducing introgression risk. In fact, at least one geneticist has expressed concern to us that no hatchery trout should be stocked in a stream containing native trout unless fish are certified 100% sterile prior to stocking. From our experience, the level of testing necessary to implement a requirement of 100% sterility is logistically impractical and cost prohibitive for any states that stock more than a handful of streams. Regardless of sterility rate, in most cases, it is a political impossibility to eliminate hatchery trout stocking in all waters that possess native trout. Although large programs cannot guarantee 100% sterility, stocked trout with high triploid induction

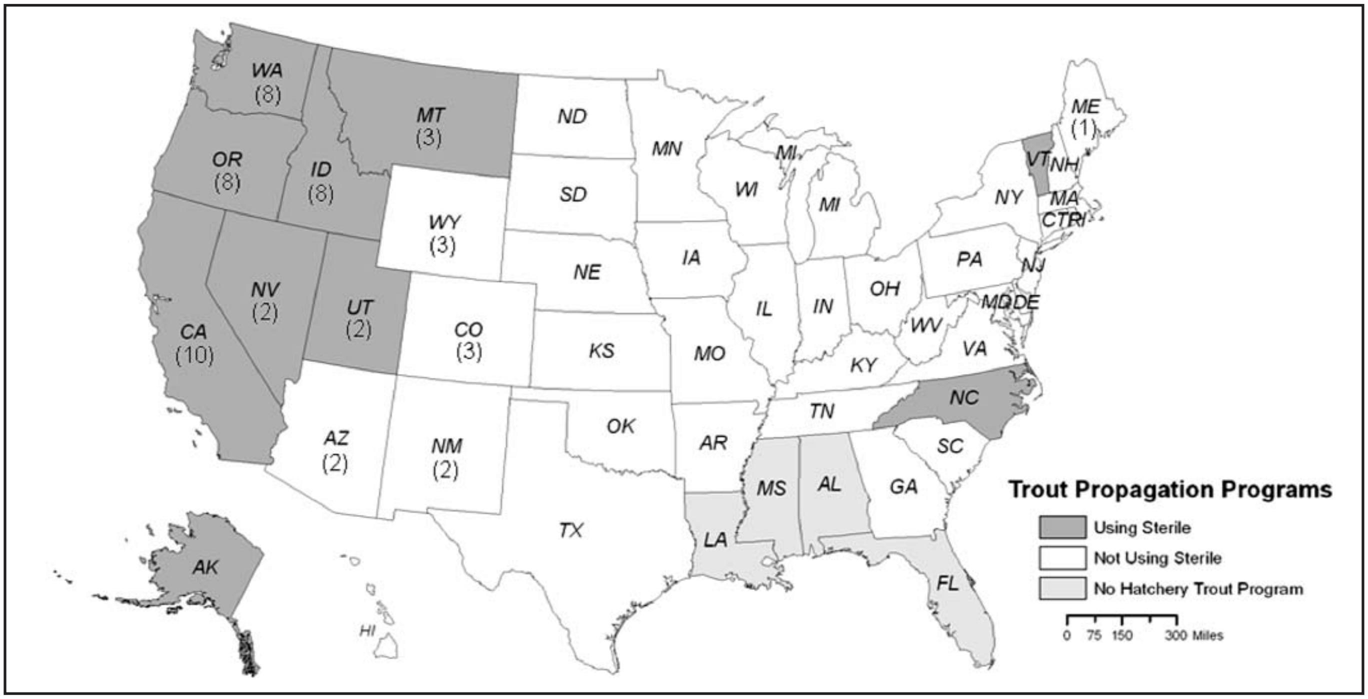
Table 3. Results from sterile fish survey conducted during July–August 2005. States are listed with U.S. Postal Service abbreviations. Please note that the proportion by species columns do not necessarily total to 100% if salmonids other than rainbow trout (RBT), brown trout (BRN), or brook trout (BRK) were stocked.

State	Hatchery stocking program	# stocked in streams (millilons)	% RBT	% BRN	% BRK	Sterilization program	Wild trout management philosophy	Sterilization techniques	Sterilization program status	Commercial egg purchases	# of eggs taken in-state (millions)	# of ESA listed petitioned species
AL	no	0.000	0	0	0	no	no wild pops	--	--	no	0.00	0
AK	yes	2.000	75	0	0	yes	conserve genetic integrity	heat	functional	no	1.80	0
AZ	yes	0.300	84	1	0	no	don't stock on wild pops	--	--	yes	1.00	2
AR	yes	2.500	97	1	1	no	no native pops	--	--	no	0.00	0
CA	yes	1.850	90	5	3	yes	don't stock on wild pops	pressure	experimental	yes	15.00	10
CO	yes	4.200	0	0	0	no	limited recruitment of rbt	--	--	no	16.00	3
CT	yes	1.000	30	55	15	no	don't stock on wild pops	--	--	no	2.00	0
DE	yes	0.038	96	4	0	no	no native pops	--	--	no	0.00	0
FL	no	0.000	0	0	0	no	no wild pops	--	--	no	0.00	0
GA	yes	1.000	80	20	0	no	don't stock on wild pops	--	--	no	0.00	0
HI	yes	0.005	100	0	0	no	no native pops	--	--	yes	0.00	0
ID	yes	0.600	100	0	0	yes	conserve genetic integrity	both	functional	yes	10.00	8
IL	yes	0.005	0	100	0	no	no wild pops	--	--	no	0.00	0
IN	yes	0.050	100	0	0	no	no wild pops	--	--	no	0.21	0
IA	yes	0.500	61	32	7	no	don't stock on wild pops	--	--	no	1.00	0
KS	yes	0.030	100	0	0	no	no native pops	--	--	no	0.00	0
KY	yes	0.250	88	12	0	no	no wild pops	--	--	no	0.00	0
LA	no	0.000	0	0	0	no	no wild pops	--	--	no	0.00	0
ME	yes	0.200	5	15	80	no	assume negligible effects	--	--	no	1.75	1
MD	yes	0.375	80	20	0	no	don't stock on wild pops	--	--	yes	0.00	0
MA	yes	0.300	62	22	15	no	don't stock on wild pops	--	--	no	0.50	0
MI	yes	5.500	30	30	0	no	locally adapted stocks	--	--	no	17.30	0
MN	yes	1.630	45	50	2	no	locally adapted stocks	--	--	no	7.50	0
MS	no	0.000	0	0	0	no	no wild pops	--	--	no	0.00	0
MO	yes	1.200	99	1	0	no	don't stock on wild pops	--	--	no	9.00	0
MT	yes	0.020	12.5	12.5	0	yes	conserve genetic integrity	heat	experimental	no	7.85	3
NE	yes	0.005	50	50	0	no	no native pops	--	--	no	0.00	0
NV	yes	2.000	70	10	10	yes	conserve genetic integrity	heat	both	yes	1.60	2
NH	yes	1.000	20	10	70	no	assume negligible effects	--	--	no	2.00	0
NJ	yes	0.600	40	20	40	no	don't stock on wild pops	--	--	no	2.30	0
NM	yes	1.500	95	1	0	no	barriers	--	--	yes	7.20	2
NY	yes	1.500	30	60	10	no	assume negligible effects	--	--	yes	6.00	0
NC	yes	0.800	40	20	40	yes	conserve genetic integrity	heat	experimental	yes	2.50	0
ND	yes	0.003	100	0	0	no	no native pops	--	--	no	1.00	0
OH	yes	0.425	94	6	0	no	don't stock on wild pops	--	--	no	0.95	0
OK	yes	2.670	80	20	0	no	no wild pops	--	--	no	0.00	0
OR	yes	0.050	100	0	0	yes	conserve genetic integrity	heat	functional	no	12.00	8
PA	yes	4.700	50	30	18	no	don't stock on wild pops	--	--	no	10.00	0
RI	yes	0.030	34	33	33	no	assume negligible effects	--	--	yes	0.20	0
SC	yes	0.080	70	20	10	no	don't stock on wild pops	--	--	no	1.80	0
SD	yes	0.017	100	0	0	no	no native pops	--	--	no	0.00	0
TN	yes	1.900	83	16	1	no	don't stock on wild pops	--	--	no	1.05	0
TX	yes	0.003	100	0	0	no	don't stock on wild pops	--	--	no	0.0.0	0
UT	yes	2.00	90	0	0	yes	conserve genetic integrity	--	experimetnal	no	27.00	2
VT	yes	4.00	34	33	33	yes	conserve genetic integrity	heat	both	no	8.00	0
VA	yes	1.00	60	20	20	no	assume negligible effects	--	--	no	2.50	0
WA	yes	0.00	0	0	0	yes	conserve genetic integrity	both	experimental	no	35.00	8
WV	yes	0.70	80	10	10	no	don't stock on wild pops	--	--	no	3.5	0
WI	yes	2.00	16	66	17	no	locally adapted stocks	--	--	no	8.00	0
WY	yes	1.60	34	4	1	no	don't stock on wild pops	--	--	no	18.50	3

can greatly reduce introgression risks compared to past stocking practices. By using heat- or pressure-shocked salmonids, we argue that the hybridization potential of a stocked group is reduced by an amount directly equal to its triploidy induction rate.

Individual states will have to weigh the costs and benefits of using sterile trout. We believe the largest cost for producing sterile trout is caused by decreased survival prior to and during hatch. From our experience and those from the literature, survival of triploid trout eggs is 85–95% that of untreated eggs (Brock et al. 1994; Galbreath et al. 1994). To maintain production levels, broodstock facilities would have to take approximately 5 to 15% more eggs. This may require additional brood fish and slightly higher rearing and feeding costs. Higher egg mortality also means that additional egg-picking effort is needed. Use of automated egg pickers in most production hatcheries means this cost

Figure 3. Occurrence and distribution of hatchery trout programs, sterile fish programs, and Endangered Species Act (ESA) influenced stocks of salmonids. The number of ESA influenced stocks, if any are present, are listed in parentheses under the states' abbreviation. These include species or subspecies that are petitioned for listing and those that are actually listed as threatened or endangered under the ESA.



would be minimal. Additional short-term costs include research efforts to develop triploid production techniques, testing of triploidy induction rates, evaluations of performance in recreational fisheries, as well as the purchase or construction of sterilization equipment. When placed in perspective with annual hatchery and research budgets in most states, we believe that the costs from higher egg mortality, additional broodfish, and research efforts to produce sterile fish at the production level are inconsequential relative to the benefits received.

Research costs to develop egg sterilization treatments can be minimized with efficient study designs and with established treatments as a starting point. It is important that multiple treatments are compared across similar groups of eggs. Ideally, well-mixed groups of eggs should be split into equal-sized sub-groups and spread among several treatments and a control. For heat treatment development, this may require multiple heat shocking units or, less preferably, using delayed fertilization to allow temperature adjustments. For pressure treatment, having multiple units is often too expensive; therefore, more creative experimental designs must be used. Due to the short duration of pressure treatments (often 5 minutes), several variations of minutes after fertilization may be tested from the same groups of eggs with ease. Of utmost importance, multiple replicates should be included to characterize variability in triploidy induction and survival rates.

Our agency, the Idaho Department of Fish and Game, has elected to develop and use mixed-sex lines of sterile fish. Techniques for developing mixed-sex sterile lines as opposed to all-female lines are more straightforward and are more easily integrated into production hatcheries. However, techniques for developing all-female lines are available (Chourrout and Quillet 1982; Bye and Lincoln 1986) and have been used extensively by commercial operations. Despite greater complexity during production, all-female lines of sterile fish may offer greater benefits for fisheries management programs. Since sterile males develop secondary sex characteristics and attempt to spawn, sterile males may suffer higher mortality rates than sterile females who exhibit no spawning behaviors (Warrilow et al. 1997). Thus, use of all-female lines could potentially make more fish available for recreational harvest. Secondly, if mixed-sex lines of fish are stocked in waters where wild fish are present, spawning attempts by sterile males with wild females may reduce the reproductive potential of wild populations. Based on the typically low survival rates observed for hatchery trout in streams (Miller 1953; Wiley it al. 1993), we believe this risk is very low; nonetheless, all-female lines would be an additional layer of protection for native stocks.

The primary benefit of sterile hatchery fish programs is conservation of native stocks. According to Epifanio (2000), 37 states possess at least 1 native salmonid species. With only 10 states currently using or investigating the use of sterile trout, we argue that further expansion of such programs could improve conservation efforts in at least some of the 27 states that have native salmonids but no sterile trout programs. Although some of these states have adopted wild trout management policies of not stocking directly on wild or native populations, use of sterile trout in addition to this management scenario could still be beneficial. Hatchery trout are known to migrate from their stocking locations, sometimes substantial distances (Bjornn and Mallett 1964; Bettinger and Bettoli 2002). Use of heat- or pressure-treated trout prevents a large majority of mobile hatchery fish from breeding with adjacent native populations. Secondly, illegal fish translocations have become increasingly common (McNeill 1995; McMahon and Bennett 1996). Use of sterile trout prevents or at least greatly reduces the possibility that translocated trout will establish populations or breed with native populations. Also, stocking of hatchery trout by members of the general public in privately-owned water bodies has plagued

This production-scale heat bath was designed and built by IDFG personnel.

This hydrostatic pressure chamber also used to produce sterile triploids for rainbow trout and, experimentally, for several other salmonid species. Pressure-treated eggs appear to have higher survival and more consistent triploidy rates than heat-shocked eggs. It is likely that this unit will replace the heat-shock bath in large-scale triploid production for Idaho sport fisheries.

fisheries managers for decades (Greene 1957). Requirement of sterile trout in these situations would provide additional protection to native populations by preventing establishment of non-native salmonids and, depending on species, subsequent hybridization (Waters 1999).

As an added benefit, several field studies suggest that use of sterile trout may actually improve recreational fisheries. Sterile trout may have higher survival rates due to the reduction in spawning mortality. Warrillow et al. (1997) documented high emigration and subsequent mortality rates of diploid brook trout from Adirondack lakes that lacked adequate spawning habitat. Stocking of all-female triploid brook trout into these systems reduced emigration rates and associated mortality resulting in enhanced age and size structure. Similarly, Teuscher et al. (2003) noted that survival rates of triploid rainbow trout in two Idaho reservoirs over a 4-year period were higher than those of diploids, possibly for the same reasons. Sterile trout also may have greater longevity, allowing greater harvest opportunities from a particular stocked cohort. For example, Johnston et al. (1993) documented that triploid kokanee lived up to 2 years longer than their diploid counterparts.

Most field evaluations, including our own, have used paired designs to assess the performance of triploid fish in fisheries. While these designs have many benefits, they also have at least one potential flaw that may affect interpretation of results. By stocking diploid and triploid groups at the same time in a common environment, competition may become a factor. When reared together in tanks, diploid fish out-compete triploid fish for food and grow at higher rates (Lincoln and Bye 1987; Galbreath et al. 1994). While we speculate that competition had little effect on the results of our stream study (catchables were used) or our reservoir study (very productive systems were used), it may partially explain the poor survival of triploid fish in oligotrophic high mountain lakes. Alternative study designs may need to be considered to fully address the central question for these type of studies which is, "Do triploid fish provide adequate fisheries when stocked alone?"

Although we believe the use of sterile hatchery trout can be beneficial in many instances, sterile fish are not a panacea. In large-scale production efforts, it is impossible to guarantee 100% triploidy induction rates. Therefore, we do not recommend that states develop sterile trout to expand their stocking programs into sensitive waters. Instead, we recommend their use as a tool to reduce potential for introgression from existing stocking locations. Furthermore, sterile trout should only be used after careful evaluation. From our experience, sterile trout perform well when stocked as catchables in streams, and as fingerlings in productive reservoirs. In contrast, performance of sterile fish in high elevation lakes seems to be poor, possibly due to the harsh conditions prevalent in these habitats, such as limited food resources, cold temperatures, and low dissolved oxygen concentrations during winter. In fact, the consistent poor performance of sterile fish in Idaho high mountain lakes to date has caused us to consider further study in lowland lentic systems with questionable water quality, an area where limited past research suggested performance issues (Simon et al. 1993).

According to our phone survey results, we documented a strong regional trend in interest and use of sterile trout among state hatchery programs, with minimal interest and experience by states east of the Mississippi and relatively strong interest in Pacific Northwest states and Alaska. While the presence of numerous, wide-ranging populations of native salmonids in the western Unites States partially explains this geographic trend in stocking sterile trout, we speculate that the spate of ESA-related petitions and formal listings for salmonids in Pacific Northwest streams was the catalyst for this discrepancy. Although good progress has been made primarily in the western states, further expansion of sterile trout programs to include sterilization of all domesticated strains of hatchery trout could improve long-term conservation efforts. This may be particularly true for eastern states within the native distribution of brook trout, where interest in sterilizing hatchery salmonids has lagged.

Our phone survey indicated that most states with hatchery trout programs possess their own broodstocks (34 out of 46 states). These states can develop their own sterile trout programs at nominal cost with the steps outlined earlier in this document. Federal hatcheries are also an important egg source to many state hatchery trout programs. Currently, no federal hatcheries are producing or supplying triploid trout eggs to state programs, partially due to lack of requests for sterile trout from participating states (Steve Brimm, U.S. Fish and Wildlife Service, pers. comm.). For those states without their own broodstocks, sterile eggs and fish may be purchased from a variety of commercial sources. According to Cam Timm of Troutlodge, Inc., the largest trout egg supplier in the world, prices for mixed-sex diploid rainbow trout eyed eggs are US $15–17 per 1,000 eggs, while all-female triploid rainbow trout sell for US $30–34 per 1,000 eggs. Quotes of relative prices for diploid and all-female triploid brook trout were similar. Mixed-sex diploid brook trout eyed eggs sell for US $17.50 per 1,000 eggs, while all-female triploid brook trout are sold for US $40.50 per 1,000 eggs. We are aware of only one commercial supplier of triploid brook trout, Pisciculture des Alléghanys Inc. (Saint-Philémon, Quebec, Canada). Neither of these companies currently sells mixed-sex triploid progeny. Though the cost of all-female triploid eggs is approximately double that of diploid eggs, it is important to note that egg costs are typically only a small percentage of overall production costs in most hatchery programs.

CONCLUSION

Our experience in developing a sterile trout program suggests sterilization techniques applicable to large-scale production efforts, as well as field evaluation of recreational fisheries, is both straight forward and inexpensive. We encourage fish culture personnel and fisheries managers in other states and provinces to consider development, evaluation, and implementation of sterile trout programs for their recreational fisheries when feasible. Despite our obvious enthusiasm for sterile fish use in recreational fisheries, they are not a panacea in all settings, and we call for additional field evaluations in states developing such programs.

ACKNOWLEDGEMENTS

We would like to thank a host of hatchery managers and employees who have labored on the IDFG sterile trout program. Also, we thank fisheries biologist, hatchery managers, and administrators from the 50 states for answering a barrage of telephone survey questions with no advance warning. Their willingness to roughly estimate the size and nature of their hatchery programs allowed us to examine the status of sterile fish programs in the United States. Bob Carline, Virgil Moore, and two anonymous reviewers provided thoughtful critiques of an earlier version of this document.

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Appendix 1. Phone survey questionnaire.

1. Do you have a hatchery stocking program for salmonids? (Yes/No) _______
   a. If yes, go to question 2
   b. If no, then go to question 9

2. How many hatchery trout do you stock in streams statewide annually? ___

3. What species do you stock (Proportion by species)? __________________

4. Do you have any ongoing programs for sterilizing hatchery salmonids in your state? (Yes/No) _____
   a. If Yes, Ask why?
      Growth/size __
      Conservation __
      Other: ____
   b. If No, ask how do you manage around genetic conflicts between hatchery stocking and wild trout management?
      Stock other species __
      Assume no effect __
      Don't stock wild trout streams __
      Other: ____

5. What method(s) are you using to produce sterile fish? ________________

6. Is your sterile program experimental or functional at the production level? ____

7. Do you buy trout eggs from commercial suppliers? (Y/N)

8. If you produce hatchery fish from your own broodstocks, roughly how many eggs do you take annually? _____

9. How many species of salmonids in your state are in the ESA arena (petitioned for protection, or actually listed)._____

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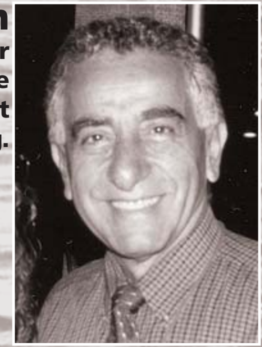

Our Students, Our Lifeline

AFS can be proud of the way it keeps opening doors for student participation in its affairs. Several years ago, the AFS Governing Board voted to add a representative from the Student Subsection at its meetings. That was a wise decision. It served a dual purpose: it helped the highest elected body of AFS governance become aware of the particular concerns of student members who constitute some 15% of the membership. It also helped the representatives of our student membership learn the workings of such governance and the issues confronting a thriving scientific professional organization.

The experience gained there translates into preparing students to assume leadership roles, not only in AFS but also in their future careers. Some of these student unit leaders have already assumed major duties within AFS as chairs of committees and other such tasks.

Even before Governing Board participation, students have been consistently encouraged to attend the Annual Meetings of the Society by lowering their registration fees or by providing special travel awards for attendance. The Skinner award program stands out in its achievements in that regard.

Recognizing the need for nurturing professionalism beyond student years, AFS then started the Young Professional membership category with reduced dues (valid for three years after graduation) to help young members in their transition from a student status to a full-blown career. And last year AFS went even further by reducing student membership dues to a nominal $19 a year and giving students full and free access to all journal material published by AFS since 1872. This was followed immediately by several Sections reducing or eliminating the dues that Sections charge to their student members. As time goes by, we should expect to see other Sections following suit.

In other words, barriers to full participation by student members in all aspects of "AFS life" have been lowered substantially and it is now up to students and the student members of AFS in particular to take advantage of such opportunities and to challenge the more established leadership by bringing in new ideas and contributions.

Attending the student colloquium at the Anchorage meeting last year, however, I was reminded that we still have a long way to go to increase participation of minorities and women in AFS and fisheries in general. Minorities in particular face a host of roadblocks ranging from lack of access to quality education, low-income homes, and a lack of awareness of mentoring and internship programs available to minorities.

Certainly AFS can do more in that regard by helping in networking for minority and women student members, as well as relaying the information that membership in AFS is a step up the ladder of career professionalism. The second edition of *An AFS Guide to Fisheries Employment* will be helpful in that regard. It is also a great resource for all students and young people as it covers all aspects of professionalism from academia to administration.

REPORT:
RESOURCE POLICY COMMITTEE

Economic Growth and Fish Conservation

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Views and opinions presented by the units involved do not necessarily represent those of the authors' employers.

INTRODUCTION

At its 2005 Annual Meeting, the American Fisheries Society (AFS) Governing Board asked the Resource Policy Committee (RPC), in partnership with the Socioeconomics Section (SES) and the Water Quality Section (WQS), to develop a study report summarizing the relationship between economic growth and fish conservation. This article is intended to update readers on that effort, and will be supported by a verbal report with alternatives to the Governing Board in Lake Placid in September 2006. The Board will then decide whether to ask the three Units to prepare an AFS policy statement on economic growth and, if so, which alternative direction would be preferred by AFS leadership.

Economic growth and fish conservation represents an intersection of human population growth, open access to public trust resources, resource consumption, and fish conservation, with the latter including water quality and related environmental concerns, the species, and harvest. In approaching such a complex assignment, the Committee and Sections recognized that socioeconomics, water quality, and fisheries trends are intertwined and difficult to separate in terms of their influence on fish conservation. Their collective effort provides some underlying basis for economic principles, resource trends, and ecological principles related to fish conservation. Our hope is that this article, and perhaps a more detailed study report that could lead to an AFS policy statement, will illuminate both the relationship between economic growth and fish conservation and a possible role for AFS.

This subject has proven to be quite controversial. AFS members working on earlier drafts of our study reports offered different opinions on approach and recommendations. Because consensus could not be reached among the three AFS Units contributing intellectual energy to this effort, our work to date is best presented in differing positions on the central issues. Accordingly, this article includes an opening statement by the Water Quality Section followed by a statement by the Socioeconomics Section.

FINDINGS AND POLICY PROPOSAL OF THE AFS WATER QUALITY SECTION

On 16 February 2005, the Society's WQS formally requested that the RPC consider a policy position on economic growth and fish conservation. The WQS had previously concluded, as verified by a vote of its membership, that economic growth—increasing production and consumption of goods and services—was incompatible with water quality and fish conservation, including the conservation of fish species, the ecosystems they depend on, and harvestable fisheries. The formal process of AFS position-taking was engaged, and this article represents one stage in the process.

As explained above, AFS established a committee to produce a draft study report on the relationship of economic growth to fish conservation. Ultimately the draft study report was not sanctioned by the SES representatives.

This article is a condensed version of the draft study report on economic growth and fish conservation as sanctioned by the WQS. For the sake of conserving space, references are not provided here but are available in the draft study report, posted at www.fisheries.org/html/stewardship.shtml.

Economic growth is an increase in the level of national product, income, and expenditure. It occurs via increasing population and per capita consumption, where "consumption" refers to that of households, firms, and government. Economic growth is indicated by increasing gross domestic product (GDP) or gross national product (GNP).

U.S. and North American economies have grown continually throughout their histories. In recent decades, the U.S. economy grew at a rate of approximately 2.5% per year. By the end of 2005, U.S., Canadian, and Mexican GDP were $12.37, $1.08, and $1.06 trillion, respectively. Population growth and economic growth are virtually inextricable. All else equal, an economy grows at the rate of its population. Historically, however, North American economies have grown as a result of per capita consumption growth as well as population growth. In the United States, for example, per capita consumption is now more than four times its 1900 level.

It is theoretically possible to have economic growth based exclusively on growth in per capita consumption. However, population growth provides firms with more labor and consumers, and the government with more taxpayers. Public policy that directly or indirectly encourages population growth is usually motivated out of concerns for economic growth. Therefore, it is impractical to address the issue of population growth in the policy arena without concomitantly addressing the issue of economic growth.

Major fisheries and fish species are in decline worldwide. These include species from primary consumers to the "super-carnivores" occupying the highest trophic levels; 90% of large predatory fish species are depleted in the oceans. At least 364 North American freshwater fishes are endangered, threatened, or vulnerable. This situation can be attributed to two main causes: overfishing and habitat degradation.

The linkage of economic growth to overfishing is clear. As the economy grows via population, there are more mouths to feed and, all else equal, more fish eaten. As the economy grows via per capita consumption (which entails per capita income), wealthier consumers tend to eat higher in the trophic levels and eat more fish relative to less expensive foods.

The linkage of economic growth to habitat degradation is just as clear. When we look at the causes of habitat degradation, these causes invariably represent sectors, infrastructure, or byproducts of the economy. The sectors include such prominent economic activities as agriculture, mining, logging, ranching, and fishing. Examples of infrastructure include roads, power plants, and dams. The byproducts of economic production are generally referred to as pollution.

It is also worth noting the connection of economic growth to three other prominent threats to fish conservation: invasive species, urbanization, and global warming. Invasive species travel the globe as a function of commerce, often via ballast waters, the aquarium trade, and deliberate stocking of sport and forage fish. Urbanization represents the concentrated proliferation of the labor force, light manufacturing, and service sectors, resulting in pronounced alteration of natural habitats. Global warming is a function of economic activity, and nowhere is this clearer than in the United States where the economy is 85% fossil-fueled.

Humans are ultimately limited by such ecosystem goods and services as soil, water, minerals, primary production, renewable and non-renewable fuels, natural pathogen controls, and natural air and water purification. The less each human consumes, the more (or longer) humans (or other species) may be supported. Theoretically, the ultimate carrying capacity would be reached when all individuals in the population were using the bare minimum of resources to survive and all available resources were being used. If each human consumed twice as much, then the planet could support one-half as many. In other words, human carrying capacity may not be described solely in terms of population, nor solely in terms of per capita consumption, but rather in terms of population times per capita consumption, i.e., in terms of the size of the economy as indicated or approximated by GDP.

Principles of ecology add essential context for understanding the relationship of economic growth to fish conservation. Due to the tremendous breadth of the human niche, which continues to expand with new technology, the human economy grows at the competitive exclusion of nonhuman species in the aggregate, including fish and other species. That growth also substantially alters the structure and function of aquatic and marine ecosystems.

Invention and innovation, or "technological progress," have allowed *Homo sapiens* to broaden its niche dramatically at the competitive exclusion of other species. Yet there is another side of technological progress cited by those who do not acknowledge a fundamental conflict between economic growth and biodiversity conservation. In purely economic terms, technological progress refers to increasing output (of goods and services) per unit input (of land, labor, and capital). If this aspect of technological progress was predominant, then perhaps economic growth could be reconciled with biodiversity conservation. This prospect is sometimes referred to as "green growth."

The WQS does not view this prospect as valid, much less likely. When technological progress occurs in the context of economic growth as a national goal, the efficiency gains are not used to conserve input (land, labor, and capital) in the aggregate. Rather, when the goal is economic growth, the input that may have been conserved is used instead to obtain more output (goods and services).

Economic growth policy has been left entirely to politicians and economists. Fisheries and aquatic science must be advanced for purposes of informed economic policy-making. The mission of AFS is "to improve the conservation and sustainability of fishery resources and aquatic ecosystems by advancing fisheries and aquatic science and promoting the development of fisheries professionals." It seems clear that the "conservation and sustainability of fishery resources" will not "improve" when: (1) there is a fundamental conflict between economic growth and fish conservation, and (2) economic growth is among nations' highest priorities. Both of these conditions exist, and only the second is malleable. The AFS mission includes the qualifier, "by advancing fisheries and aquatic science." It is precisely such science that has been omitted from policy discussions relevant to economic growth and fish conservation.

A steady state economy occurs when there is a stable or mildly fluctuating production and consumption of goods and services, which entails stable or mildly fluctuating population times per capita consumption. A steady state economy is not limited to a particular kind of political or economic system such as a capitalist democracy or a communist dictatorship.

It is unrealistic to expect the public and policy makers to immediately embrace the steady state economy as an immediate policy goal, although it is reasonable to expect the public and policy makers to slowly accept the appropriateness of a steady state economy as a long-term policy goal. In the interim, society must consider short-term approaches, or "stepping stones" toward a steady state economy. These stepping stones amount to lowered rates of economic growth. Therefore, it behooves the AFS to support a downward trend in the rate of economic growth. As the economic growth rate decreases, the rate of natural capital depletion will also decrease as will the decline of fish species and biodiversity.

Unlike a steady state economy, a gradually declining rate of economic growth is something that may be advocated and implemented immediately, because it is the normal course of affairs in economic policy-making to debate and negotiate preferred rates of economic growth. In the United States, for example, such dialogue regularly occurs among the Council of Economic Advisors, Federal Reserve System, and Department of Commerce, with various amounts of input from the public and other entities. The parties to the dialogue cannot do an adequate job of considering the public welfare without information on the conflict between economic growth and various aspects of environmental protection and ecological integrity, including fish conservation. Such information is unlikely to come, in a compelling and reputable manner, from sources other than professional natural resources societies.

Given the findings presented in the draft study report, the WQS proposes that the following position on economic growth (preceded if necessary by a preamble) be considered for adoption by the AFS:

Whereas,

(1) Economic growth is an increase in the production and consumption of goods and services, and;

(2) Economic growth occurs when there is an increase in the product of population multiplied by the per capita production and consumption of households, firms, and government entities, and;

(3) Economic growth is indicated by increasing real gross domestic product (GDP) or real gross national product (GNP), and;

(4) Economies grow as integrated wholes consisting of agricultural, extractive, manufacturing, and services sectors that require physical inputs and produce wastes, and;

(5) Based upon established principles of physics and ecology, there is a limit to economic growth, and;

(6) A steady state economy is an economy with stabilized (or mildly fluctuating) production and consumption of goods and services, and with a stabilized (or mildly fluctuating) product of population multiplied by per capita consumption, and;

(7) A steady state economy is generally indicated by stabilized (or mildly fluctuating) real gross domestic product (GDP) or real gross national product (GNP).

Therefore,

(1) There is a fundamental conflict between economic growth and fish conservation based on ecological principles including niche breadth, carrying capacity, and competitive exclusion, and;

(2) Technological progress occurs via research and development that requires funding and the use of natural resources, has many positive and negative ecological and economic effects, and may not be depended upon to reconcile the conflict between economic growth and fish conservation, and;

(3) A steady state economy is a viable, sustainable alternative to a growing economy, especially in the larger, wealthier American economies, and;

(4) The long-run sustainability of a steady state economy requires its establishment at a size that does not breach ecological and economic capacity during expected or unexpected supply shocks such as droughts and energy shortages, and;

(5) A steady state economy does not preclude economic development, a qualitative process in which different technologies may be employed and the relative prominence of economic sectors may evolve, and;

(6) A steady state economy is ultimately required for the conservation of fish, the ecosystems they depend upon, and harvestable fisheries, and;

(7) Macroeconomic and microeconomic policy tools may be used in tandem to gradually reduce rates of economic growth pursuant to the long-run goal of a steady state economy, and;

(8) Economic policy tools for human population stabilization may be carefully and gradually introduced for purposes of achieving sustainable, healthy economies including sustainable, healthy fish populations and fisheries.

An AFS policy statement on economic growth does not necessarily need to be explicit on which policy tools would be used to temper economic growth and to strive for the establishment of a steady state economy. However, we offer some observations on policy tools that could be incorporated in the statement if necessary.

Policy tools for fish conservation may be thought of in conventional economic terms as microeconomic and macroeconomic. An example of a microeconomic policy tool is an individual transferable quota, or ITQ, which is a transferable share of a Total Allowable Catch (TAC). The share may be sold or leased. An ITQ/TAC system falls under the general category of "cap-and-trade" systems. An ITQ/TAC system is conducive to the sustainability of a fishery, but is not a sufficient condition for sustainability. Fisheries are affected by a wide variety of variables, including various economic sectors operating upstream.

Another example is a tax on pollution. Polluters may be taxed to compensate for the costs to society of the pollution. Pollution is a major threat to fish conservation, and the fisheries profession should support all efforts to establish taxes that "internalize" the social costs (including degradation of fisheries and their ecosystems) of pollution.

Macroeconomic policies are roughly divided into fiscal and monetary. Fiscal policy refers to government expenditure and the financing thereof, most notably via taxes. Total expenditure and total taxes influence the scale of an economy. In general, increased expenditure has an expanding effect on scale, and increased taxes have a contractionary effect.

Monetary policy refers to the manipulation of the money supply and interest rates, which in turn affect each other. Along with fiscal policy, monetary policy is a blunt tool for affecting the scale of the economy. Expanding the money supply and decreasing interest rates have the general effect of expanding scale. These actions tend to stimulate spending (especially in the case of lowering interest rates) and investment, which stimulates the establishment and expansion of housing, infrastructure, and industry. The money supply may be expanded by reducing reserve requirements, i.e., the fraction of bank deposits that must be held on demand, buying government bonds on the open market, and lowering the interest rate.

Facing a fundamental conflict between economic growth and fish conservation, it is appropriate for the AFS to support macroeconomic and microeconomic policy reforms conducive to a steady state economy. These should be advocated in a way that makes it clear that an immediate transition from a growing economy to a steady state economy is both virtually impossible and highly undesirable. Instead, the AFS should advocate a cautious and gradual transition toward a steady state economy.

No credible set of economic policy recommendations for sustainability would be complete without addressing population growth. All else equal, population growth results in economic growth and is, along with the economic growth it contributes to, unsustainable. As with fish conservation, population growth may be addressed with economic tools. For example, certain aspects of the U.S. and state tax codes provide incentives for having children. The most obvious example is a per-dependent tax break for parents. Tax breaks could be provided for having no children, or for the first child, and eliminated for further children. A more stringent approach would entail a graduated tax on parents based on the number of children and the parent's income.

SOCIOECONOMICS SECTION COMMENTS ON THE "DRAFT STUDY REPORT AND POLICY STATEMENT ON ECONOMIC GROWTH AND FISHERIES"

The "Draft Study Report and Policy Statement on Economic Growth and Fisheries" authored by the RPC and WQS work group identifies major fish conservation issues and problems in the United States and the world. The report argues that macroeconomic growth is the primary source of these problems and identifies one preferred alternative to the goal of macroeconomic growth: a zero growth, steady state economy. That alternative is explained by the WQS in the preceding section of this article.

While the SES agrees that fisheries face many problems, the SES disagrees that a steady-state economy would solve them. The Socioeconomics Section is concerned about five issues. Finally, the SES offers two alternative policy suggestions designed to improve fish conservation without gross negative impacts on the rest of the economy (See the spring issue of the Socioeconomics Section newsletter for an expanded version of these comments: www.fisheries.org/socioecon).

The focus on economic growth and not the broader concern of economic development is justified by a false dichotomy. Economic development is defined as "qualitative change, realization of potential, evolution toward an improved, but not larger, structure or system" and economic growth as "increase in the real level of national product, income, and expenditure." These definitions ignore the relationship between growth and development. Economic growth is one component of economic development. These are not necessarily competing objectives.

Achieving a goal of zero economic growth would require contractionary macroeconomic policy. The two major macro policy instruments currently used in the United States are monetary policy and fiscal policy. While one can use monetary and fiscal policy in an attempt to control economic growth, these are blunt, untargeted policies, and their links to the environment are tenuous at best. Indeed, the pursuit of zero macroeconomic growth with contractionary macroeconomic policy could cause the perverse result of degrading the environment.

Macroeconomic growth is the product of population growth and per capita gross domestic product (GDP) growth. GDP is a measure of aggregate, i.e., macro, economic performance. It is microeconomic activity, not macroeconomic growth, that contributes to overfishing, pollution and other environmental problems. As such, microeconomic policies, e.g., pollution taxes, are more appropriate policies for the goal of fish conservation.

The positive correlation between GDP and threatened and endangered species listings is the only empirical evidence advanced to support the goal of a steady state economy. This evidence is weak for several reasons. First, as the RPC/ WQS draft study report is clear to state, correlation does not imply causality. Second, the time-series econometric model confuses stock and flow variables. Third, listing decisions are imperfect measures of endangered status. In contrast, the SES estimates similar models considering the issues raised above. Using similar time-series data and cross-section data the SES finds no empirical evidence to support the claim that per-capita GDP negatively impacts fish conservation. Models suggest that the problem is population growth.

Relationships between economic growth and fish conservation are extremely complex, and it is an oversimplification to assert that merely stopping growth will benefit fisheries. Even if it could be proven that a steady state economy is ultimately required for sustainability, left unanswered are critical questions such as who chooses which steady state, and who are the winners and losers of said choice?

The divergent goals of maximum economic growth and zero economic growth is a false choice. There is much middle ground. A goal of sustainable development is an alternative. Also, since gross domestic product is a flawed measure of economic growth and development, so-called Green GDP measures are alternatives that incorporate environmental quality. Pursuit of economic growth in green GDP is a viable alternative to a steady state economy. With these alternatives, households and business firms are not constrained by contractionary macroeconomic policy, but their negative impact on the environment is constrained with microeconomic-based environmental policy.

The AFS should focus on policies that educate economic experts, government leaders, and the public about the negatives associated with unregulated economic activity. The AFS should argue that society should pursue more fisheries conservation, not by imposing strict limits on GDP, but because it is in the best interests of society due to the increasing social costs of continued environmental degradation.

CONCLUSIONS

This article presents the differing views of two AFS Sections. The challenge before our Society is to weigh these and other options as we decide whether one could form the basis of a Society policy statement. Such statements form the basis for the Society's position on legislation, budgets, and decisions, and are of educational use for the public and policymakers. The discussion leading up to Lake Placid, and likely continuing beyond, will be robust. We encourage your participation, whether through a Chapter, Division, Section, Committee, or as an individual.